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CONTROLLED IMAGE DESIGNS:

Results from the first installations

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Summary

This Report describes the results of measurements carried out in the first practical implementations of the Controlled Image Design principles, for the BBC's Baseband Project in Broadcasting House, London. They confirmed that the main acoustic objectives were achieved at least as well as in the experimental room. However, the initial results showed that there were strong early reflections from the top of the mixing desks, as a result of small errors in the locations of loudspeakers, mixing desks and listening positions. A second set of measurements, after some minor remedial work, showed that those defects had been eliminated. Measurements of the Controlled Image Design installation in the new Transcription Service multi-channel, post-production suite E1 showed that all of the design objectives had been achieved directly.

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CONTROLLED IMAGE DESIGNS: Results from the first installations

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1. INTRODUCTION

The high frequency acoustic problems of contemporary studio control rooms have been discussed.[1] A design principle which allows more comfortable and consistent monitoring for stereophony has also been described.[2, 3, 4] It gives special emphasis to the reduction of reflected sound energy reaching the listener within about 20 ms of the direct sound.

In principle, the magnitude of the early reflected energy can be controlled by redirecting it away from the main listening position. In the experimental work, a target for the exclusion window had been set initially at −20 dB for the first 20 ms, based on the evidence then available. Experimentally, it was found to be impractical to achieve such a target in moderately-sized control rooms. The demonstrations and evaluation of the experimental room had been carried out with some reflections of the order of −14 dB relative to the direct sound. With further experience, it seemed clear that the original target was unnecessarily stringent, as well as being impractical. Based on the subjective results from the experimental room, a more practical target, of −15 dB for 15 ms, seemed to be sufficient to reduce the effects of early reflections to insignificance.

Following a series of subjective evaluations of the experimental room by operational staff and project managers, the decision was taken to use the new design principles for the refurbishment of the control cubicles of three Broadcasting House, London, basement areas B12, B13 and B14 as part of Project 'Baseband'. Somewhat later, the decision was also taken to use the design principle for a new multi-channel, post-production suite for Transcription Service in Bush House, ultimately to be called E1.

This Report presents the results of measurements carried in the completed rooms. In the case of the B12, B13 and B14 areas, it was immediately discovered that a number of small discrepancies had led to incorrect positioning of the loudspeakers in relation to the mixing desk and the main listening position. This led to strong, isolated reflections reaching the listener's ear from the top surface of the mixing desk. (It was corrected before the rooms were finally completed. The results contained here for that condition are, therefore, obsolete and should not be taken to represent the finished rooms. They remain as a record of the first measurements in new facilities built to a new acoustic design and provide a guide to the sensitivity of the design process.)

The reflection from the top surface of the mixing desk is difficult to avoid, with the typical layout geometry. At best, it can usually only be directed at about the listener's chest height. Small errors in desk slope angle, loudspeaker height, listener-seated ear height and the plan positions of all of these elements can easily result in a distinctly measurable reflection amplitude at a listener's ear. Whether or not it is subjectively very significant is less certain. However, it undoubtedly accounts for large changes in the perceived stereophonic image quality with variations in head position, in *any* design of control room.

A second set of measurements was carried out in B12, B13 and B14 following that remedial work. Measurements were also carried out in E1, when the construction had been completed. In response to serious complaints from the users of B12, it was necessary to carry out further investigations and remedial work.

This Report is intended to be a record of the objective performances of a new approach to control room acoustic design. Mention here of features of the acoustic responses as a function of time and frequency does not necessarily mean that those features will be subjectively significant.

2. PROJECT DETAILS

2.1 B12 cubicle

The control cubicle for B12 was relatively long and narrow, with the observation window to the left-hand side. The location of the window required that it be built into one of the reflecting panels. The length of the room was more than adequate to delay the first reflections from the rear wall by more than 20 ms.

Fig. 1* shows the Controlled Image Design sketches supplied to the project team.

2.2 B13 and B14 cubicles

The control cubicles for B13 and B14 were required to be oriented with the larger room dimension forming the width of the cubicle. This led to a very wide design, which allowed the addition of second observation windows. This gave additional sight lines into the studios – especially from the producer's position. It also meant that the front-to-back dimension of the room was only just adequate to meet a 15 ms time-window criterion.

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* For ease of use, all figures have been placed separately in a fold-out section.

The two cubicles were designed as exact mirror images of each other. The observation windows were located in the front. The main entrance door was formed in one of the acoustically reflecting side surfaces.

Fig. 2 shows the Controlled Image Design sketches for Cubicle B13.

2.3 Transcription service E1

For the relocation of Transcription Service to Bush House, a new set of technical facilities were constructed in an area of the ground floor of Bush House, South-East Wing. Amongst the facilities was a replacement for Kensington House T1 (control room), to be called 'E1'. The room was designated as a 'multi-track, post-production suite'.

Fig. 3 shows the design sketch as supplied to the project team.

3. MEASUREMENTS

3.1 Outline

The measurement of short-time acoustic events is necessarily limited in frequency resolution. It is a fundamental physical property that the product of time and frequency resolutions is a constant, approximately equal to unity. Thus, to make statements about time intervals of the order of a few milliseconds implies frequency resolutions of around 1 kHz.

Ref. 5 contains a detailed discussion of acoustic measurements in the time and frequency domains, and the styles of presentation of the results.

There are two measures of time-domain responses that are particularly useful in the study of acoustic early reflections in relatively small rooms – the so-called 'Energy-Time' response (ET) and the three-dimensional Energy-Frequency-Time response (EFT). Both of these types of display are used for the results in this Report. The measurement sampling frequency was 30 kHz and the input filter cutoff frequency was 10 kHz. In most cases, a degree of truncation of the results has been applied in order to hide the less significant data. The measurements were carried out using an MLSSA analyser.[6] The microphone position was the nominal centre-listening position, equidistant from both loudspeakers, as specified for the design.

Fig. 4 shows a typical full range ET response. The direct sound is indicated by the first peak, normalised to 0 dB at a time of about 0.2 ms relative to the display origin. This is followed by a reflection at 1.2 ms at an amplitude of about −15 dB. Other reflections follow, with discrete ones at about 7.5, 9.5, 16.2, 16.9, . . . , 23.9 ms. All of these later reflections are around −20 dB or lower. In fact, in the response shown in Fig. 4, the 'direct sound' actually contains a significant reflection at about 0.6 ms, with an amplitude of about −6 dB. This is not resolved by this method of display. It can be inferred from other data processing discussed later. Most of the other ET response plots presented have been truncated at the −24 dB level to reduce the background clutter.

Fig. 5 shows a typical EFT response, for the same data as in Fig. 4. The logarithmic frequency axis runs from left to right, from 1 kHz to 10 kHz. The time axis runs from rear to front, from 0 ms to about 24 ms. The amplitude axis is in decibels vertically, 6 dB per division. The STFT* length was 128 samples, corresponding to a nominal input block length of about 4.25 ms. The STFT transform window was half-Hanning. A one-third octave smoothing function was applied, in the frequency domain, to reduce the time-frequency artifacts which result in specious irregularities of frequency response. This was justified by the assumption that the reflected sound would be a relatively smooth function of frequency. The general background clutter arises from two causes. One is diffraction of sound in the room. Despite the angling of surfaces to redirect the main sound energy, a residue of uncontrolled sound remains in the region of the main listening position because of diffraction at the edges of the reflectors. A second element of the background can arise as a result of the sideband performance of the STFT and its associated windowing function. With the Hanning window used this is probably not a significant factor in these results. To reduce the visual effects of the clutter, most of the other EFT response plots presented have been truncated at approximately −16 dB relative to the direct sound (*time* = 0) level .

3.2 All Broadcasting House areas

When first measured in all of the Broadcasting House areas, there were reflections from the mixing desk control surface. These had arisen because the loudspeakers had been positioned about 240 mm higher and about 75 mm further away from the front wall than in the design. The nominal listening position relative to the mixing desk was also wrong by about 100 mm because of a misunderstanding about reference positions. All of these factors added together to make the desktop reflections worse than they should have been.

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* STFT — Short-Term Fourier Transform.

All of the results also show, or at least imply, that there was an even earlier reflection, at about 0.6 ms. This is not easily visible in the time-domain results. The EFT results show, in every case, a strong dip centred at about 2300 – 2400 Hz for the time = 0 frequency response. This corresponds to a half- wavelength of about 73 mm. The only physical object which would have given that path length difference was the top of the desk upstand, the surface of which was steeply angled, specifically to avoid such an effect. It was also possible that the loudspeaker itself was producing that effect, perhaps because of the spacing between the two drive units. (Geometrically, that difference should have been about 28 mm, giving a first cancellation at about 6 kHz.) The other possibility connected with loudspeakers themselves is a time delay in the crossover filter. However, no such effects have been seen in loudspeaker measurements carried out in a free-field environment. This 'reflection' was not noticed at the time of the measurements and required further investigation. It is discussed further in Section 4.

In several cases, there was a second-order reflection from the top of the desk upstand, via one of the reflecting ceiling panels. That panel was not angled to deal with sound energy from such a direction and caused a measurable reflection at the listening position, with a total time delay of about 7 ms.

3.3 B12 cubicle

3.3.1 B12 left-hand loudspeaker

Although B12 cubicle was large enough to control reflections from the boundary surfaces within the first 20 ms using the CID approach, a large quantity of additional furniture and fixed shelving units had been added to the basic acoustic design. Some of this furniture was quite large and was connected by a wiring loom to the wall. Despite moving it as far as possible and by the use of a studio acoustic screen as a shield, it was impossible to prevent reflections occurring at about 15 – 20 ms from these additional structures.

Fig. 6 and 7 show the ET and EFT responses for the left-hand loudspeaker with no measures taken to reduce the desktop reflection – either the early one at 0.9 ms or the secondary one at 7.5 ms. These are both evident in Fig. 6. Also clearly evident is the group around 15 – 20 ms. Overall, the levels of most reflections (except those from the desktop) are –18 dB or less. In the EFT response, the reflections at 14 – 20 ms from the additional furniture and the secondary ceiling reflection at 7.5 ms are clearly visible. The desktop reflection at 0.9 ms is only just evident in the time domain of the EFT response; it is almost completely hidden by the effects of the STFT window. In the frequency domain, it was responsible for the large irregularities in the 'direct' frequency response.

Figs, 8 and 9 show the same measurement with an absorber placed on the desktop surface, to reduce the 7 ms secondary reflection. This was done largely as a diagnostic test to identify the path of this reflection. It reduced the amplitude by about 5 dB. It also had a small effect on the 0.9 ms reflection, reducing it by about 3 dB.

3.3.2 B12 right-hand loudspeaker

Figs. 10, 11, 12 and 13 show the results obtained for right-hand loudspeaker, the same conditions as for the left-hand one.

Here the reflections from the additional furniture and fittings occurred earlier, from about 12 ms onwards. This was caused by a computer console which could not easily be moved or shielded. The levels were also somewhat higher. The early desktop reflection was at about 1.1 ms and the same secondary reflection is visible, at 7.5 ms. Comparison of Fig. 11 with Fig. 7 shows that the desktop reflections were significantly higher for the right-hand side. In Fig. 11 the reflections from about 12 ms were also clearly higher.

3.4 B13 cubicle

B13 Cubicle also had some additional furniture, located in the left rear corner, capable of creating acoustic reflections.

3.4.1 B13 left-hand loudspeaker

Fig. 14 shows that the early desktop reflection was at about 1 ms and was very strong, only about 6 or 7 dB below the direct sound. The secondary desktop reflection at 6.5 ms, is hardly visible. In that room, the distance between the rear wall and the listening position caused first reflections from the rear at about 15 ms. Those reflections are visible in Fig. 14, although the levels were fairly low, partly because of the acoustic absorption on that surface. Without the absorption, that level would have been expected to have been about –11 dB. This demonstrated that the absorbers were further attenuating the sound, by about 6 dB. This was in general agreement with other measurements of the reflection coefficient of high-frequency modular absorbers. This reflection was also surrounded by others, probably from the additional furniture in the room.

Fig. 15 shows the EFT response for the same data. The group of reflections at about 15 ms are clearly visible. This response suggests a reasonably uniform high frequency reflection coefficient, with a slight peak at about 3 kHz. This was not unreasonable for A3 modular absorbers with fabric covering.

3.4.2 B13 right-hand loudspeaker

Figs. 16 and 17 show the ET and EFT responses for the right-hand loudspeaker. It should be noted that the time axis labelling on Fig. 16 is different from the earlier ones. It shows absolute times rather than time relative to the direct sound. (The reason for this was an obscure and unidentified inconsistency in the measuring instrumentation. All future references, in this Report, to the times of acoustic events will be given as times relative to the arrival of the direct sound at the measurement position.) About 6 ms should be subtracted from the absolute time axis values to give the relative time.

Despite the geometric symmetry of the room, there are some significant differences between the results for the right-hand and left-hand loudspeakers. In particular, the reflection from the rear wall, at about 13.5 ms, was isolated. This was because the reflections from the furniture were later than for the left-hand loudspeaker (around 17 ms) and rather lower in amplitude (as would be expected from the additional path length).

3.5 B14 cubicle

B14 Cubicle was designed to be exactly the mirror image of Cubicle B13. Again, the time axis of the ET response is absolute rather than relative.

3.5.1 B14 left-hand loudspeaker

Figs. 18 and 19 show the ET and EFT results for the left-hand loudspeaker.

Because the room was expected to be the same as B13 Cubicle, and appeared to be so, no detailed investigations were carried out at the time of the measurements. However, minor differences in geometry, especially in connection with the very critical, possibly diffraction-limited, desktop reflection, resulted in quite marked detail differences.

The very early time interval, up to about 3 ms, was characterised by a number of strong reflections. The one at about 0.6 ms is visible, although its apparent level is too low to cause the dip in the steady-state frequency response at 2.3 kHz. It was at the limits of resolution and was, perhaps, being mis-represented by the measurement system. The desktop reflection at 1 ms was strong, and appears to have been accompanied by a second reflection 0.2 ms later. These were followed by minor reflections at about 2.2 and 3 ms, from an unidentified object. Clearly, the reflections from the top of the mixing desk were, in this case, a complicated matter. The secondary ceiling reflection was also evident.

Reflection amplitudes from the rear wall were fairly small. The later-time results are similar to those of B13 for right-hand loudspeaker, as would be expected from the mirror-image symmetry. The EFT response, Fig. 19, confirms the ET results and shows that the reflected energy in the period up to about 7 ms is centred on about 4 kHz.

3.5.2 B14 right-hand loudspeaker

Figs. 20 and 21 show responses very similar to those for B13 left-hand loudspeaker (see Figs. 14 and 15), as expected.

4. OVERALL FEATURES OF THE BROADCASTING HOUSE AREAS

Fig. 22 shows a typical ET response over larger ranges of time and amplitude (for B13, left-hand loudspeaker). The response has been filtered to the frequency band 1 kHz to 4 kHz in order to illustrate the features more clearly. On that scale, the divisions between the direct sound, the initial time delay gap and the later reverberation are very clear (although the direct sound was contaminated, in that case, by the unwanted desktop reflection). The direct sound was followed by a gap of about 14 ms to the beginning of the reasonably steady, reverberant decay. In the gap, reflections were of the order of –20 dB below the direct sound. In the later part of the response, only minor departures from a smooth distribution of reflections occurred, a slight excess at 30 – 40 ms being followed by a slight shortfall at 45 – 55 ms.

Similar features can be seen in the Schroeder plot[7] shown in Fig. 23. It shows a strong direct sound component, followed by a reasonably constant response to 14 ms (because there is very little energy to integrate) and then a fairly uniform decay. In Fig. 24, the same Schroeder plot on expanded axes shows the same early regularity. In contrast, Fig. 25 shows that for a conventional design (Edinburgh Cubicle 1) the early Schroeder plot is characterised by a large degree of irregularity, especially in the period up to about 15 ms.

One notable and consistent feature of the EFT results for all of the Broadcasting House area is the dip at about 2300 Hz in the direct sound (*time* = 0) response. This has already been briefly discussed. That it is not an artifact of the measurement system nor of LS5/8 loudspeakers can be seen from Fig. 26, measured in Edinburgh Cubicle 1 (in 1991). In that case, although the early time response contained strong ceiling reflections at about 3 ms, the direct sound response was reasonably flat.

On a more conventional type of plot, Fig. 27 shows a typical frequency response, calculated for the first 3 ms of the time response (B12, left-hand loudspeaker), which again illustrates the effect. The dip at 2378 Hz is, arguably, the third harmonic of the cancellation at 794 Hz due to a reflection path length difference of 217 mm, or about 0.6 ms. This view is reinforced by some evidence in Fig. 27 of the remainder of the comb-filter response, at multiples of about 800 Hz. The depth of the ripples is about 5 dB peak-peak, suggesting a reflection amplitude of about 7 – 8 dB below the direct sound. All of this tends to confirm the existence of a fairly strong reflection at about 0.6 ms which cannot easily be distinguished in the time-domain responses.

5. DISCUSSION OF THE FIRST RESULTS FROM THE BASEBAND PROJECT

These first measured results from the Broadcasting House areas confirmed that, in principle, the objectives of the acoustic design had been achieved at least as well as in the experimental room.

However, in all of the rooms there was evidence of strong early reflections from the top of the mixing desk and its rear upstand. As a result of the first tests, some modifications were made to the room geometry. The results of those changes is reported in the Section 6.

Most of the rooms also contained furniture and fittings not included in the original acoustic design. These compromised the achievement of the original acoustic design targets of –20 dB for 20 ms. However, it was subsequently shown that those targets were unnecessarily stringent and that the underlying principle of the design could be achieved with less demanding criteria.

After the discovery of the errors in the heights of the loudspeakers and in the positions of the mixing desks (and hence the reference listening positions), recommendations were made for changes, principally to the heights of the loudspeakers. There also appeared (at that time) to be a requirement to cover at least part of the top surfaces of the upstands at the back of the mixing desks with acoustically absorbing material.

The only part of the remedial work that had been carried out at the time of the second series of measurements was the change to the heights of the loudspeakers.

6. SECOND SERIES OF MEASUREMENTS IN THE BROADCASTING HOUSE AREAS

6.1 B12 cubicle

In B12 Cubicle, the original layout had been adequate to avoid a direct geometric reflection from the desktop surface, because of the extra space available compared with B13 and B14. However, diffraction over the top of the upstand had been sufficient to produce a measurable, though low level, reflection at the reference listening position.

At the time of the second measurements, the room contained significantly more technical equipment than at the time of the first set. It appeared likely that additional reflections would be caused by this extra equipment.

6.1.1 B12 left-hand loudspeaker

Fig. 28 shows the ET response for the revised loudspeaker height. It should be compared with Fig. 6. The main desktop reflection at about 1 ms had essentially been eliminated, as had the secondary reflection from the upstand at 7.5 ms and the unidentified reflections at 9.5 ms and 17 ms. Overall, there were far fewer reflections, and those that remained were all less than –20 dB relative to the direct sound, at least those within the 20 ms target window.

Fig. 29 shows the new EFT response – compare with Fig. 7. The reduced number of reflections reaching –16 dB (the ‘floor’ of the plotted results) relative to the direct sound is clear. Also, the direct sound, at time = 0, is much more regular; the response does not show the severe dip at about 2.4 kHz that was previously evident. (Aspects of the ‘direct’ sound response will be discussed later.)

6.1.2 B12 right-hand loudspeaker

Fig. 30 shows the ET response for the revised loudspeaker height; it should be compared with Fig. 10. Again, the main desktop reflection at 1 ms had been eliminated, as had those at 6 and 7.5 ms. The number of reflections had been reduced and those that remained were all less than –20 dB relative to the direct sound, at least those within the 20 ms target window.

Fig. 31 shows the new EFT response – compare with Fig. 11. The reduced number of reflections reaching −16 dB relative to the direct sound is again obvious. As with the left-hand speaker, the direct sound was much more regular.

A new feature was the rather large peak at about 3 kHz/15 ms, about −10 dB relative to the direct sound. Despite intensive investigation, the path of this reflection could not be identified. It was clearly leaving the loudspeaker at about 45° upwards in elevation and on-axis in plan. It was also, clearly, arriving at the microphone from the top left-hand front corner of the room. It had an attenuation of about the correct value for the path-length difference, indicating virtually perfect reflection(s) from whatever surfaces it was encountering. The most likely cause was thought to be a frame member supporting the first absorbing panel of the ceiling. However, it is unlikely that such a narrow-band effect at so late a time, and 10 dB below the direct sound, would be audible.

6.2 B13 cubicle

6.2.1 B13 left-hand loudspeaker

Fig. 32 shows the ET response for the revised loudspeaker height. It should be compared with Fig. 14. Once more, the previously strong desktop reflection at 1 ms has been completely eliminated, as has the small one at 6.5 ms. The total number of reflections around −20 dB relative to the direct sound has been greatly reduced, as have the amplitudes of the few which remain.

Fig. 33 shows the new EFT response, to be compared with Fig. 15. The direct sound was, again, much more regular. The interval up to about 15 ms was similarly clear of reflections, but the reflections after 15 ms appear to be worse. This may be an artifact of the presentation – with the irregular responses shown Fig. 15, it is difficult to choose the level to which the displayed 'floor' value of −16 dB can be referred. With the more regular responses from the second measurements, it is more obvious. One or two decibels difference might easily have arisen in this case, making the later response appear worse.

6.2.2 B13 right-hand loudspeaker

Fig. 34 shows the ET response for the revised loudspeaker height. It should be compared with Fig. 16. The main desktop reflection, previously very strong, at about 1 ms, was much reduced, from −8 dB to barely distinguishable. The strong reflection after 13.5 ms had also been effectively eliminated. Two small new reflections, at 7.5 and 10 ms had appeared. These were both well below −20 dB and were insignificant.

Fig. 35 shows the new EFT response – compare with Fig. 17. The direct sound was, again, much more regular. However, a strong reflection at 7.5 ms/3800 Hz had appeared, with an amplitude of −10 dB relative to the direct sound. As with the B12 cubicle, it is unlikely that such a narrow-band effect at so late a time, and 10 dB below the direct sound, would be audible.

6.3 B14 cubicle

6.3.1 B14 left-hand loudspeaker

Fig. 36 shows the ET response for the revised loudspeaker height; it should be compared with Fig. 18. The main desktop reflection at about 1 ms had been much reduced. Many other reflections had been effectively eliminated. Four isolated reflections remained, at about 7, 14.5, 21.5 and 24.5 ms. They were about −18 to −20 dB relative to the direct sound – somewhat lower than previously.

Fig. 37 shows the new EFT response – compare with Fig. 19. The direct sound was much more regular, although a moderate dip at about 5 kHz indicates a small residual reflection about 14 dB down at a time delay of 0.4 ms, corresponding to a path length difference of about 140 mm. This was likely to be an effect of the loudspeaker. The original irregularities in the very early sound, that is, at about 4 kHz at 1 – 2 ms, had been significantly reduced. The reflection at 5.5 ms had been eliminated, or at least significantly reduced in amplitude and shifted to about 8 – 9 ms. A number of additional reflections had appeared, at times after 15 ms. Some of these were due to the significant amount of additional equipment in the room. Some may have been artifacts of the threshold of the display (as described above). They were at a low level and at quite late times, so they are unlikely to be audible.

6.3.2 B14 right-hand loudspeaker

Fig. 38 shows the ET response for the revised loudspeaker height, and should be compared with Fig. 20. The main desk reflection at about 1 ms had been reduced. Many other reflections had also been reduced, leaving only one which exceeded −20 dB.

Fig. 39 shows the new EFT response – compare with Fig. 21. The direct sound was more regular, although there was clearly an anomaly at about 5 kHz/1 – 2 ms. There was also a slight low-frequency dip, centred at about 1 kHz. The original measured response was too irregular to show whether or not this was a new feature; that is, one which arose as a result of the lowering of the loudspeakers. The later time, after about 14 ms, contained much higher levels of relatively narrow-band reflections, all of them centred on about 2.5 – 3.5 kHz. These were undoubtedly caused by the additional technical equipment in the room, especially the metal-cased test instrumentation being used for electronic testing and alignment of the technical installation.

6.4 Overall features

One notable and consistent feature of the new EFT results for all of the Baseband areas are the improvements in the 'direct' sound response. Fig. 40 shows, on a more conventional type of response plot, the frequency response, calculated for the first 3 ms of the time response for B13 left-hand loudspeaker. This is directly comparable with Fig. 27. The pronounced dip at 2400 Hz has disappeared. However, much of the comb-filter effect is still present, although reduced in amplitude and shifted in frequency. It now corresponds to a time delay of about 0.35 ms and a path length difference of 120 mm. It is hard to escape the conclusion that this was an 'off axis' effect of the loudspeaker, changed by alteration of the effective radiation angle.

Contrary to the earlier conclusions, it was subsequently established that these very early effects (less than 1 ms) were probably artifacts of the loudspeaker response. At the time of writing, measurements had not been carried out on LS5/8 loudspeakers to demonstrate these effects, but some brief work on the effects of diffraction over a mixing desk upstand, involving the use of an LS3/6 loudspeaker, showed the same off-axis features. These were on a shorter timescale because of the smaller size of the loudspeaker.

Finally, Fig. 41 shows a typical full-range ET response. It is comparable with, and virtually identical to Fig. 22. The significant difference is the elimination of the desktop reflection, leaving the direct sound clearly isolated for at least the first 15 ms.

6.5 Building tolerance requirements

The dimensional tolerances required for the construction of a CID room are self-evidently more stringent than those required for the acoustic design of conventional control rooms. During the development of the designs for the Broadcasting House areas, the architectural team accepted that tolerances of ±10 mm would be achievable for the positions of the main components of the room surfaces. Such tolerances would have had no significant practical effect on the theoretical acoustic performance of the CID design. They were, however, somewhat more stringent than for ordinary studio or control room construction.

There was no evidence that such departures from the theoretical design that did exist in the completed rooms (if any), within the tolerances, caused any significant acoustic effects.

The errors that did occur, in the positions of the loudspeakers and the mixing desks, arose as a result of misunderstandings and were of the order of 75 – 250 mm. These, clearly, had significant acoustic consequences. The reflections from the top surfaces of the mixing desks are especially sensitive to geometrical errors in the positions of the loudspeakers, the mixing desk and the listener, because they will almost always occur. The only remedy is to direct them away from the listener's head position. The typical geometry of mixing desk makes it only just possible to do this to an adequate degree. Thus, changes to the geometry of the listening arrangement can easily cause the design to be compromised.

7. DISCUSSION OF RESULTS FROM THE SECOND SERIES OF MEASUREMENTS IN THE BROADCASTING HOUSE AREAS

This second set of measured results shows that significant improvements had been made to the time/frequency responses in all three areas by the lowering of the loudspeakers. The early reflections from the surfaces of the mixing desks were reduced to the point where they were almost certainly of no consequence. They were probably lower in level than in many other monitoring areas in regular use. None of this is directly related to the Controlled Image Design principle because all types of control room design potentially suffer from these desktop reflections.

The lowering of the loudspeakers has also had a beneficial effect on many of the other reflections. With only one or two anomalous exceptions, all of the later reflections were reduced in amplitude, to the point where many were no longer individually detectable.

It is possible that the profusion of additional technical equipment present in the completed rooms was beneficial in reducing the amplitude of individual reflections. It is well known, in conventional control room design, that additional equipment improves the acoustic quality of the room; that has usually been explained in terms of making the later reverberation more uniform by increasing the diffusion in the room. It is quite possible that an unrecognised benefit was also being obtained in respect of the early reflection structure. However, such rooms still have strong isolated first reflections from the room boundaries, particularly from the ceilings, which are not much affected by the equipment present and which the Controlled Image Design is intended to overcome.

Listening tests carried out in B12 cubicle showed that it appeared to be satisfactory, with sharp stereophonic images and a stable phantom centre mono image. At that point, the areas were handed over to the programme makers. The subsequent difficulties are described in Section 8.

8. THE INVESTIGATION OF THE SUBJECTIVE ACOUSTIC PROBLEMS OF B12 CUBICLE

8.1 Subjective reactions

Although the objective targets for the acoustics were satisfied (within reasonable tolerances), subsequent use by programme makers indicated that the subjective quality was thought by many to be very unsatisfactory.

The subjective problems appeared to be divisible into four distinct groups:

a) low-frequency irregularities
b) mid-band tonal colorations
c) excessive reverberance
d) poor sound quality at off-centre positions.

Of these, ‘a’ and ‘b’ could be heard even at the main centre listening position, whilst ‘c’ and ‘d’ were problems mainly in other parts of the room.

8.2 Initial considerations

The low-frequency irregularity was initially thought to be the only significant problem in the room. The LS5/8 loudspeakers originally installed showed a severe ‘shelf’ in the low-frequency response, amounting to about a 7 dB lift for all frequencies below about 220 Hz (the effect was a common feature of many of the later LS5/8 loudspeakers, but that pair appeared to be worse than most). In addition, the spacing of about 0.75 m of the loudspeakers from the walls of the room caused a ‘comb-filter’ effect with a first summation peak at about 200 Hz. The combination of these two effects caused an overall lift around 200 Hz of about 12 dB.

Although bass irregularities of similar values are sometimes encountered,[8, 9] it was felt that such a peak was too great. Therefore, electronic equalisation was installed to correct the response. Unfortunately, the first attempt at equalisation was too thorough. By almost completely correcting the 200 Hz peak, the overall response was made to be too dissimilar to other installations (in most of which the shelf in the LS5/8 response has been left untreated). It also tended to emphasise (or reveal) a higher-frequency irregularity in the loudspeaker response – at about 1 kHz. It was felt by many of those involved in the assessments that little progress could be made until the loudspeakers had been replaced.

A brief experiment had been carried out (not by this author), using another type of loudspeaker. These, however, had been installed in positions leading to very severe interference from desktop reflections and also with the centre listening position seriously off-axis. Fig. 42 shows one of the responses measured in that condition. The interference pattern caused by the desktop reflection and the high-frequency ‘droop’ caused by the incorrect orientation can be clearly seen. Not surprisingly, the loudspeakers were withdrawn by the manufacturers, partly because they felt (quite correctly) that the situation did not demonstrate the full quality of their product.

Eventually, a different pair of loudspeakers was installed, in the correct locations for the acoustic design of the room.

8.3 Measurements in B12 with the new loudspeakers

8.3.1 Results

Figs. 43 and 44 show the overall frequency responses measured for the left-hand and the right-hand loudspeakers respectively. The loudspeakers had been positioned at (essentially) the correct height and position for the acoustic design (the ‘upper’ tweeter was slightly higher and the ‘lower’ tweeter slightly lower than the single LS 5/8 tweeter on which the design had been based). Because of diffraction over the top of the desk upstand, a small, and probably insignificant, amount of comb-filtering was evident at frequencies above 4 kHz. Otherwise the responses were uniform for frequencies above 400 Hz.

At frequencies below 400 Hz the responses show some irregularities – a dip at about 350 Hz and a double peak at 200 Hz and 156 Hz.

Figs. 45 and 46 show the ET and EFT responses for the left-hand loudspeaker (those for the right being essentially identical). The early reflections were well controlled, with no wideband reflections above –24 dB (Fig. 45) and very little reflection energy of any kind above –16 dB (the threshold level of Fig. 46).

8.3.2 Investigations

Some investigations were carried out of the low-frequency irregularities shown in Figs. 43 and 44. It was thought likely that low-frequency reflections from the side or front wall surfaces were involved. At frequencies such as 200 – 300 Hz, the walls appear acoustically as relatively flat surfaces, despite the visible angles and steps which form part of the Controlled Image Design. The absorption of these effective surfaces was likely to have been quite low, because they were mostly relatively hard and massive timber panels. The small amount of absorption which was present in the steps between the main surfaces was likely to be even less effective than its visual area suggested, because the frontal area was partly occupied by framing members and because it was effectively recessed in narrow strips.

By placing absorption in different places around the right-hand loudspeaker it was established that the 200 Hz peak and the 300 – 400 Hz dips were caused by reflections from the side wall. The front wall appeared to be insignificant. The 150 Hz peak was essentially unaffected by any absorption – it is likely that it was due to room modes[8, 9] (which occur in all rooms to a degree and differ in detail from room to room but which, overall, are about the same for all rooms of similar acoustic treatment).

Fig. 47 shows a response measured for the right-hand loudspeaker, with a single column of low-frequency modular absorber boxes standing in the adjacent reveal in the wall surface. The peak at 200 Hz and the dips at 300 – 400 Hz were greatly reduced. The resulting response was relatively uniform above about 200 Hz.

8.4 Subjective considerations

8.4.1 Assessment

Subjectively, the sound quality at exactly the centre listening position was judged to be good. The replacement of the loudspeakers appeared to have removed the mid-band tonal colorations previously noted. The localisation of centre phantom mono images was excellent, without the image elevation which sometimes occurs. The subjective frequency response was also judged to be good, although the effects of the bass irregularities were noticeable. The localisation of stereophonic images was also sharp and stable. There was little impression of additional reverberance or of any 'tunnel' or 'bathroom' effect.

However, a displacement of the head from the centre listening position, even by distances as little as about 300 – 400 mm, resulted in some unpleasant subjective effects. The most noticeable of these was a relatively sudden switch to an apparently very reverberant sound.

At greater distances from the centre listening position, especially in other parts of the room, the sound quality became quite reverberant, sounding as though in a tunnel or bathroom.

Subjectively, the room seemed to be very 'live' in the front half, as judged by the sound of one's own and other voices within the room. This, at least, was as expected – the Controlled Image Design principle relates only to sound originating at the position of the main loudspeaker sources. Nevertheless, the impression of a room's acoustics derived by the occupants, as a result of their peripheral activities, may have a significant affect on their perception of the sound quality from the loudspeakers. Rooms which differ greatly in the perceived sound quality, depending on the position of the source, are uncommon, especially in an environment where rooms are usually heavily (and uniformly) acoustically treated.

8.4.2 Investigations and considerations – near to the main listening position

The boundary of the region between the more-or-less normal sound and the excessively reverberant sound was found to be quite sharp. It was evident in all directions from the design listening position, at a fairly consistent distance of about 0.2 to 0.4 m. The critical distance was smaller for sideways movements (that is, parallel to the line between the loudspeakers) than for front-back or up-down movements.

That distance was much less than the radius of the controlled-reflection circle around the main listening position. The effect was, therefore, not being caused by the sudden 'appearance' of a single reflection. A measurement was carried out at a typical location. This confirmed that no isolated early reflections were 'visible' at such a position.

The only remaining significant discovery was that the effect did not occur, or occurred to a very much smaller extent, if only one loudspeaker was being used*. This discovery was very unexpected. It had originally been intended to find on which side the excessive reverberance effect occurred for each loudspeaker. To discover that it required both loudspeakers to be operating meant that it must have been a consequence of the interference pattern between the two loudspeakers.

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* Naturally, some effects were audible — those to be expected from changes in the off-axis angle and distance. Also, at distances of more than about 1 m from the centre position, the Controlled Image Design of the room itself led to the occurrence of strong isolated reflections, which inevitably affected the sound quality at such off-centre positions.

Two spaced sources radiating the same signal will produce a 'comb-filter' interference pattern, with a first null at the frequency corresponding to a half-wavelength path difference. Fig. 48 shows the measured frequency response for both loudspeakers together, at a point corresponding to about 105 mm path-length difference. The strong comb-filter effect, with about 3.2 kHz repetition interval, is clearly evident. The peak-to-peak range of the ripples is about 10 – 12 dB, indicating an amplitude match of about 4 dB at the measurement point. Had the amplitudes been more equally matched, the notches would have been much deeper.

In a Controlled Image Design room, the loudspeaker interference pattern is, of course, relatively uncontaminated by any other discrete reflections. Sound energy which arrives indirectly at the main listening position (after the controlled time interval) will be attenuated, as a result of the spreading loss, by at least 12 dB; this is in addition to any reflection loss at any boundaries it may have encountered. The effect on the comb-filter response would be to limit the depth of the notches to about 15 dB. In B12, the largest (wideband) early reflection is about –27 dB relative to the direct sound (Fig. 45), although some frequency components may reach about –16 dB at about 3 kHz (Fig. 46). Thus, the limit to the depth of the notches in the loudspeaker interference pattern, because of other early reflections, was about 20 dB.

In rooms of conventional design, using acoustic absorption to control early reflections, the earliest reflection amplitudes (from the ceiling and walls) are usually not lower than about –3 to –6 dB. Also, there are, usually, at least two such reflections and quite commonly three. The effect of these additional components is to obscure the interference pattern due to the two loudspeakers. Certainly, the subjective effect of increased reverberance does not occur (or at least has never been reported as a problem) in most conventional control rooms. A brief test in B16 cubicle (of conventional but otherwise similar design to B12) showed that it certainly did not occur there.

Although it has not been fully investigated directly, there are no known reports (to this author) of stereophony sounding excessively reverberant off-axis in an anechoic environment. Therefore, it is probable that the effect in B12 was also connected with the 'liveness' of the front half of the room. It may be the same effect as is heard with a distant radio receiver, barely audible but tuned to the same channel as a nearby one. What should be perceived as an echo frequently sounds more like additional reverberance, even in outdoor situations where actual additional reverberance is unlikely.

8.4.3 Investigations and considerations – remainder of the room

In the parts of the room away from the main listening position, the sound quality from the loudspeakers was also quite reverberant – more so than the subjective impression of the room as a whole would have suggested.

This was unlikely to be a direct result of the same interference pattern effect as pertained for positions within the Controlled Image region. In these other parts of the room, strong early reflections were inevitably present, because of the deliberate redirection of the early sound energy away from the main listening position, in the direction of those other parts of the room. A number of reflections, with relative amplitudes and time delays of about –4 dB and 6 ms, were certain to have been present. Compared with a conventional design of room, the earliest reflections in a Controlled Image Design room, at positions outside the design controlled region, are likely to be significantly higher in level and more numerous (because of the number of hard, reflecting panels at the front of the room).

A measurement of room reverberation time was carried out. The results are shown in Fig. 49(a). An attempt was made to identify the 'live' and the 'dead' ends separately. No significant differences between the two ends could be measured. This was not surprising – the reverberation time was averaged over a range of about 30 – 40 dB (at high frequencies at least), during which time the sound energy would have travelled more than 50 m. This was a distance equal to many times the room dimensions and through an average of about 40 interactions with room and object surfaces. Thus, any local effects would have been averaged out. However, it is likely that the normal subjective impression of a room's acoustics is based on an earlier period of time, probably between about 50 ms and 100 ms. There is large body of clear experimental evidence showing that reverberance is not perceived much before 50 ms or so. The upper end of the time limit is less clear but it cannot be more than about 100 ms because that is approaching the measurement period. The ear probably applies some kind of complicated time-weighting function. It was certainly true that B12 sounded quite reverberant in the front half and less so in other parts, despite the lack of difference in objective measurements.

A particular problem had been reported at the producer's position – at the right-hand end of the mixing desk. This position was significantly off-axis and close to the right-hand loudspeaker. Even in a conventional acoustic design, the stereophonic image at such a position would be virtually non-existent. In that Controlled Image Design installation, the producer's position was on the perimeter of the design exclusion region. This meant that at least one, and possibly several, strong discrete reflections would pass through or close to that position. Most of those would be from the more distant left-hand loudspeaker, rather than the nearby right-hand one. By helping to compensate for the level difference, they would partially offset the additional distance to the left-hand loudspeaker, but would do nothing at all to help the stereophonic imaging.

A further problem reported by the users of the area was that of "the sound rattling around in the space between the desk and the front wall". That this was an illusion was adequately demonstrated by placing acoustic absorption in the space behind the mixing desk. In this admittedly brief test, no one present could positively identify an improvement. That is not to say that a small improvement, perceptible with familiarity with the room, could not be achieved by additional absorption there. Even as part of the Controlled Image Design there is an argument for making the space below and behind the mixing desk highly absorbing — to control that part of the early sound reflected down into that space by the ceiling panels.

8.5 Installation of extra absorption

For a number of reasons, as outlined above, it was thought beneficial to install some additional absorption at the front of the room.

This treatment was expected to:

a) reduce the general subjective impression of 'liveness', especially at the front of the room,

b) answer any complaints about "sound rattling around behind the desk" and particularly to:

c) reduce the impression of excessive liveness of the loudspeaker sound in the remainder of the room,

d) improve the conditions at the producer's position.

For the producer's position especially, covering at least some of the reflecting panels with efficient high frequency absorption was the only practical solution.

What could not be predicted was the effect of additional absorption on the excess reverberance perceived at positions only slightly displaced from the main listening position. At best, if the effect was really due to the 'liveness' of the front half of the room then the improvement would be significant. If it were due to some other, but unknown, factor it might have been useless.

As a test, approximately 12 m^2 of acoustic treatment was added to the front surfaces of the reflecting panels. This treatment, which was particularly effective at all frequencies above about 1 kHz, was added in a more-or-less unbroken 1.5 m wide band, between about 0.5 m and 2.0 m from the floor. It extended round the front of the room on both sides, to points approximately in line with the back edge of the mixing desk. It was not practicable to add any test treatment to the ceiling.

8.6 Measurements with extra absorption

Fig. 49(b) shows the reverberation time after the installation of the temporary treatment. In the region above about 500 Hz, the reverberation time was reduced by about 25 – 30%, from about 0.35 to 0.26. The low frequency limit of the effectiveness of the absorption was fairly extended because of the large airspaces behind the additional treatment in the temporary installation.

Fig. 50 shows the steady-state response measured for the left-hand loudspeaker. The high frequency response was essentially identical to that of Fig. 43, the same measurement without the additional acoustic treatment. The dip around 300 – 400 Hz was significantly smaller and a small change had been made to the peak at 200 Hz. Overall, the response was reasonably smooth from about 250 Hz upwards. At low frequencies, the response irregularities arose partly from the poor resolution of the Fourier Transform measurement method and partly from the effects of room modes.

Fig. 51 shows the ET curve for the first 20 ms. It is virtually identical with Fig. 45, the same measurement without the additional acoustic treatment, except that the 'peak' at 12 ms which reached –27 dB had been reduced. In that condition no wideband reflection exceeded –30 dB, which was almost certainly much better than is actually required.

Fig. 52 shows the EFT curve for the first 20 ms. Again, it is virtually identical with Fig. 46, the same measurement without the additional acoustic treatment.

8.7 Subjective assessment with extra absorption

Overall, and especially in the front half of the room, the subjective impression of the room as a whole was of less reverberance.

Further listening tests showed that the sound quality and the stereophonic imaging at the main central listening position were essentially unaffected. The onset of apparently excessive reverberance (with movements away from the centre of the order of 200 – 300 mm) was at least very much reduced, if not completely eliminated.

The sound quality for larger displacements, that is, over most of the width of the mixing desk, was also much improved; although the normal effects of moving so far away from from the optimum position were, of course, still present.

At the producer's position, the sound quality was much improved, with far less of the excessive reverberance. Inevitably, the stereophonic imaging remained seriously compromised by the extreme off-centre location.

In the remainder of the room, the sound quality was also much improved, although a significant amount of excess reverberance remained evident. This residual effect may be due to the shape of the room, being rather long and narrow, especially when viewed from the rear tape machines.

8.8 Recommendations for remedial treatment

It was recommended that panels of high-frequency acoustic treatment should be installed on all of the front reflecting panels. It should cover the height range around seated and standing heights, with some extension.

It was also recommended that the producer's position should be moved so that it was in line with the main listening position.

It was accepted that the resulting room would depart somewhat from the original design brief – which was to create a room with a longer reverberation time than many recent control cubicles had achieved.

9. RESULTS FROM TRANSCRIPTION SERVICE E1

9.1 Measurements

9.1.1 Wideband 'Energy-Time' curves

Fig. 53 shows the ET response for the left-hand loudspeaker and Fig. 54 the ET response for the right-hand loudspeaker.

In the other cases in this Report, these responses have been plotted on a scale extending down to –24 dB relative to the direct sound. In the case of E1, such plots would show very little. Therefore, the scale has been extended downwards to –36 dB. (As stated previously, for obscure instrumental reasons, the time scales of the two results appear to be different – that for the left-hand loudspeaker includes the absolute time offset due to the propagation direct path delay. The relative time periods and the horizontal scale are, in fact, the same for both results, showing the first 35 ms of the time response.)

When it is considered that the original target had been for the control of the reflected energy to be better than –15 dB for 20 ms (relative to the direct sound), these results were very satisfactory. With only one exception, for neither loudspeaker did any reflection exceed –21 dB during the first 30 ms (at least). The one exception was a single reflection or small group of reflections around 1.8 ms, more evident in the result for the right-hand loudspeaker. The origin of these reflections was not identified but, at levels below –18 dB relative to the direct sound, they were not of any acoustic consequence.

9.1.2 Energy-Time-Frequency responses

Figs. 55 and 56 show the EFT responses for the left-hand and right-hand loudspeakers. Again, these plots are usually drawn for a total range of levels of 16 dB (in order to reduce the 'clutter' and produce a clearer presentation of the important data); but in this case the scale has been extended to show a range of 20 dB, i.e. the 'floor' of the plotted response has been set at –20 dB relative to the direct sound.

These responses were also reasonably free from anomalies, except for a set of fairly regularly-spaced reflections with maximum energies around 5800 Hz. In both cases, the earliest of these reached a level of –12 dB at a relative time of about 7 ms. This corresponded to a path-length difference of about 2.33 m.

The cause of this reflection was, at first, thought to be from the timber structure of the transition panel from the CID ceiling structure to the conventional suspended ceiling over the remainder of the room. But, when first measured for the left-hand loudspeaker, this reflection had been very strong – it measured about –12 dB even in the wideband ET response. Later, however, it seemed to have disappeared; it could not be identified at all in the wideband response. The only change made in the room had been in the orientation of one of the operational lighting fittings over the tape recorders on the left-hand side of the room. In Fig. 55, a narrow-band reflection at about 7 ms centred on about

5800 Hz is evident at a level of –12 dB relative to the direct sound. This may be the residue of that reflection from the nearest light fitting. The lower-amplitude reflections, near the same centre frequency, near 9.8, 15 and 21 ms, suggest the regular pattern of the spacing of the light fittings and tend to confirm that interpretation.

This uncertainty was not resolved at the time of the measurements and would have required further investigation. However, the effects are narrow-band and at or below –12 dB relative to the direct sound. They are unlikely to be subjectively perceptible.

Also just visible in Figs. 55 and 56, especially in Fig. 55, are the reflections at 1.8 ms referred to in the previous section.

9.1.3 Filtered Energy-Time responses

In an attempt to evaluate the possible reflections from the operational light fittings, the time response for a band of frequencies around 5800 Hz were plotted on an ET response curve.

Figs. 57 and 58 show these filtered ET responses for the left-hand and right-hand loudspeakers. The filter centre frequency was 5800 Hz with a bandwidth of one third of an octave. These responses are, effectively, sections through the data of Figs. 55 and 56 at 5800 Hz, along the time axis. The time and frequency response resolutions are similar, although the dynamic range displayed by Figs. 57 and 58 is larger.

The occurrence of frequency-selective reflections from some sort of regular structure is quite evident. In fact, figures 57 and 58 suggest that more than one regular structure was involved. Those could have been the two lines of light fittings, one running from front to back of the room, somewhat to the left of the room centre line, and the second running across the width of the room, behind the main operating position at the mixing desk. Once again, it must be stated that these effects are unlikely to be subjectively perceptible. They have been discussed here purely for completion of this record of the measurements.

9.2 Overall features and discussion of results from E1

Overall, the time-frequency responses from both the left-hand and right-hand loudspeakers easily meet the target specification of –15 dB for 20 ms. As in all such areas, some narrowband features of the responses are somewhat higher than the general level and, in this case, slightly exceed the target specification at some frequencies and time instants.

These results are similar to, but slightly better than those obtained from the London Broadcasting House Baseband project. However, both easily meet the target specification, at least in the time interval up to 15 ms, where the restricted lengths of B13/B14 limited the control of rear-wall reflections after that time. The probable reason for the small number of higher-level reflections in the Broadcasting House areas was the presence of a quantity of desks and other furniture extending above seated shoulder height. In E1, apart from tape machines around the walls, all of the additional equipment was lower. The built-in loudspeakers of E1, which led to a simpler CID structure with fewer discontinuities, may also have contributed to the slightly better results.

At the time of these measurements, the technical facilities did not allow listening tests to be carried out easily. Other tests, by the eventual users of the area, were carried out later and the first results were promising: subsequently, the users expressed complete satisfaction with the room's acoustics.

10. CONCLUSIONS

The first acoustic tests on areas incorporating a new approach to control room acoustic design showed that the basic acoustic objectives had been achieved to a sufficient degree. The main layout and structure of the room geometry were found to be satisfactory. A number of additional items of furniture and fittings, whilst very necessary, were not included in the original design and have compromised the original targets. However, it appears that those original targets were unnecessarily stringent.

The first measurements also showed that a number of minor defects and oversights had occurred. These arose mostly from assumptions made independently by different groups of specialists.

In any future similar development, it is important that all of the details of the layout are checked and that no assumptions are made about the normal standards adopted by different groups of specialists.

Further measurements, carried out after the loudspeakers' positions had been adjusted, showed that the lowering of the loudspeakers to their design height almost entirely eliminated the problems of the very early reflections from the surfaces of the mixing desks. This remedial action also materially reduced the amplitudes of most of the later reflections, although one or two anomalous results were obtained, none of which are likely to produce audible effects.

These first installations of Controlled Image Design control rooms highlighted a number of important factors. The sound quality and the stereophonic imaging at the centre listening positions in all of the rooms were excellent (given well-matched loudspeakers) but the quality of both deteriorated rapidly even for relatively small displacements.

Given that the design-control was concentrated on the main listening position, it was inevitable that areas well outside this would have monitoring problems. In B12, this especially applied to the producer at the right-hand end of the desk and to the tape operators at the left-hand side and behind the controlled area. The choice of Controlled Image Design was inappropriate if good listening conditions at those extreme locations were important design requirements. It is, however, unclear how good conditions could be provided at those locations by *any* kind of acoustic design. Nevertheless, the contrast given by the CID process may tend to exacerbate perception of the uncontrolled areas.

The recommendation for additional acoustic treatment should reduce most of the unwanted effects, without departing from the concept of controlling the early reflections. Indeed, with the additional treatment, the control of the first reflections is enhanced. The effective reduction of these reflections by the combination of angled surfaces and acoustic absorption should be very much greater than it is in rooms of simple rectangular form, whatever the form of their acoustic treatment (excluding special measurement chambers).

The work has also highlighted some weaknesses in the design and understanding of loudspeakers and their responses, especially in relation to three-dimensional, time and frequency responses.

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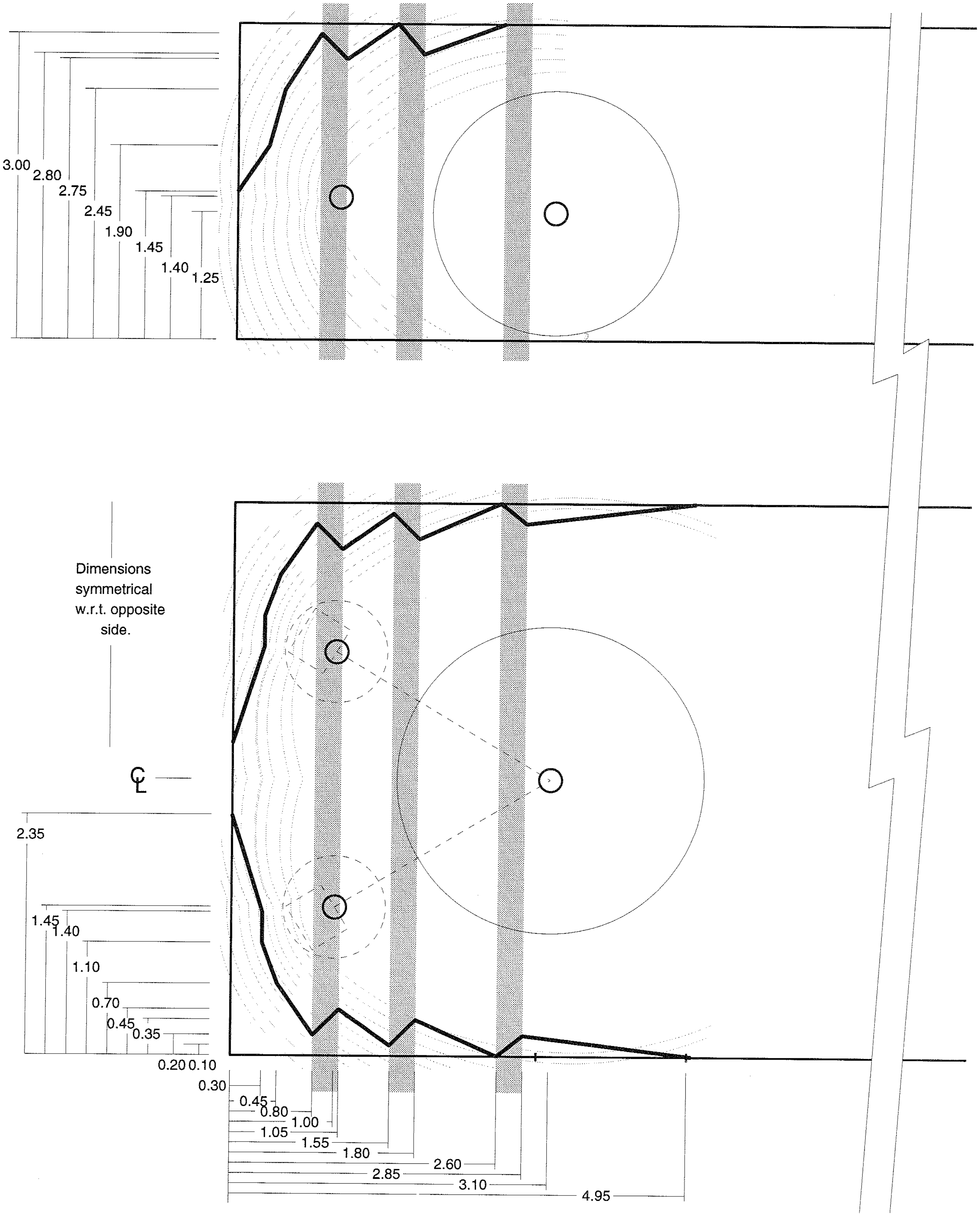
12. ACKNOWLEDGEMENTS

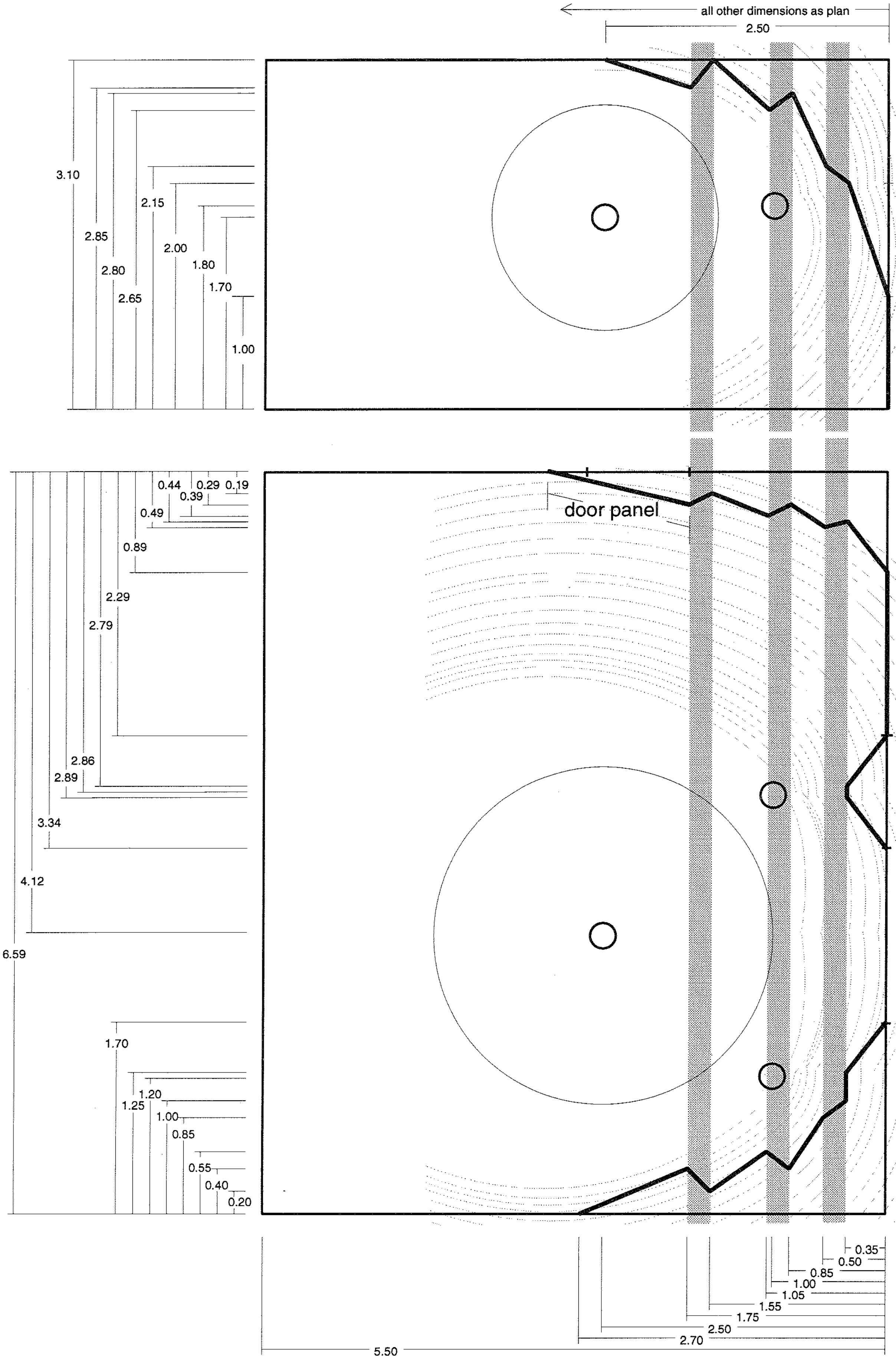
This Report has described the background to two new acoustics projects, the results and interpretation of measurements in respect of the Controlled Image Design. However, the complete design of any facility is a joint effort, involving many specialists. In particular, the remainder of the internal acoustic designs were carried out by A.R. Woolf (B12, B13 and B14) and R. Cole (E1) of BBC Building Design Services.

Figures



NOTE - Shaded areas represent absorption, all other surfaces reflective

Fig. 1 - Sketch showing outline plans for B12 as supplied to the project team (dimensions in metres).



NOTE Shaded areas represent acoustic absorption.

Fig. 2 - Sketch showing Controlled Image Design for B13 (dimensions in metres).

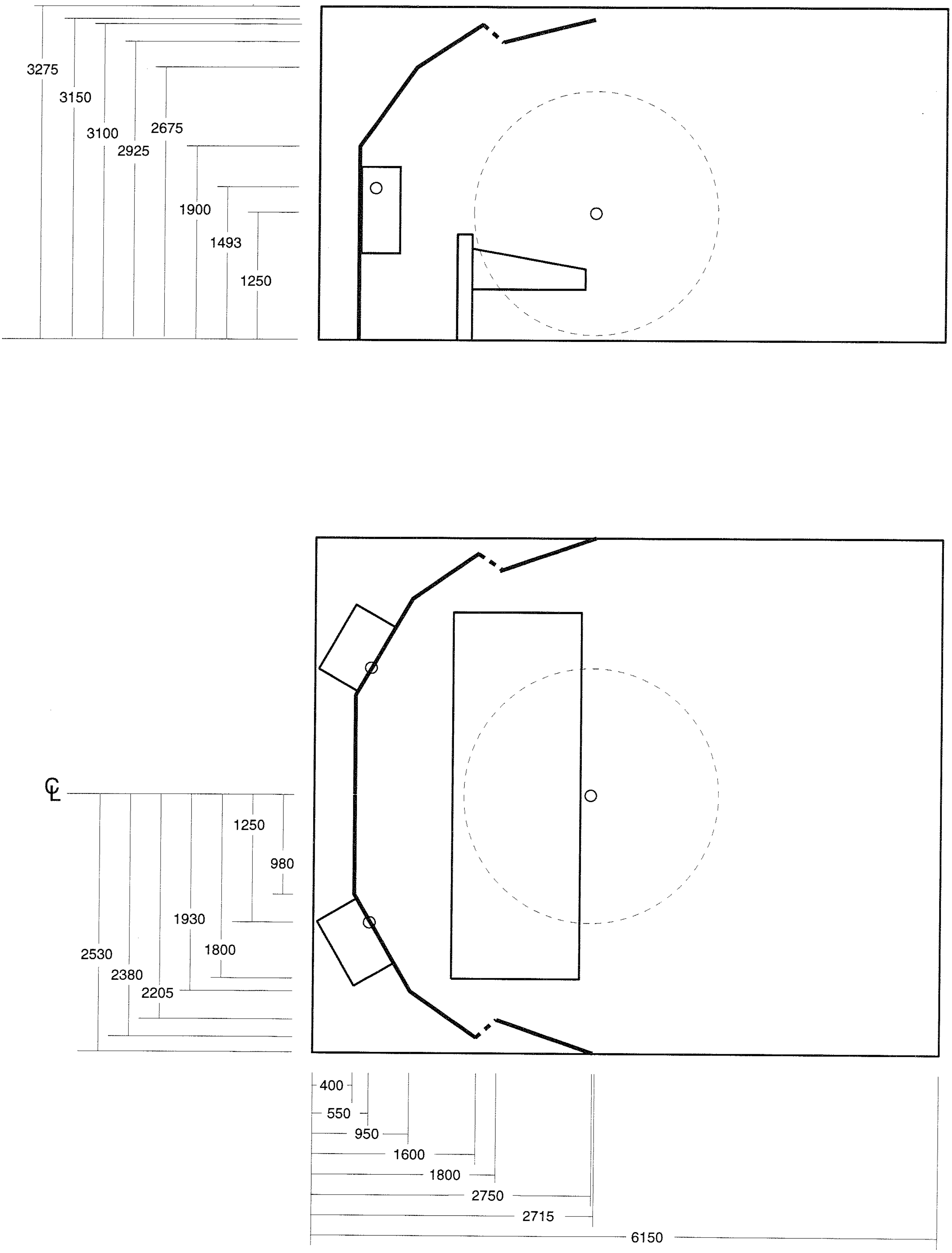


Fig. 3 - Sketch showing Controlled Image Design for E1 (dimensions in millimetres).

(R009)

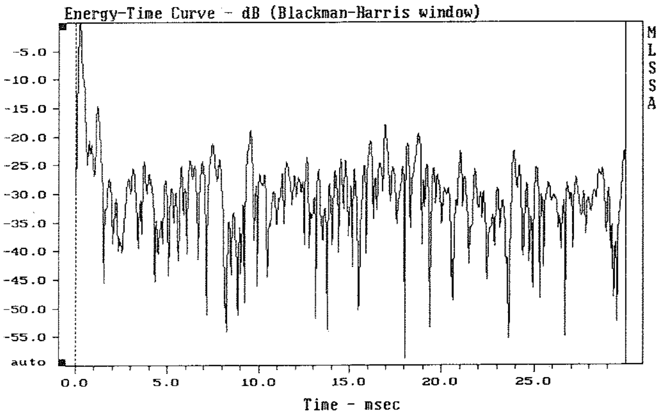


Fig. 4 - Full-range Energy-Time response.

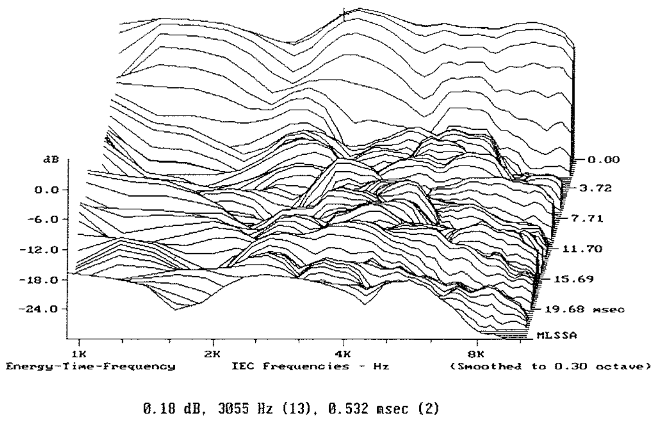


Fig. 5 - Full-range Energy-Frequency-Time response.

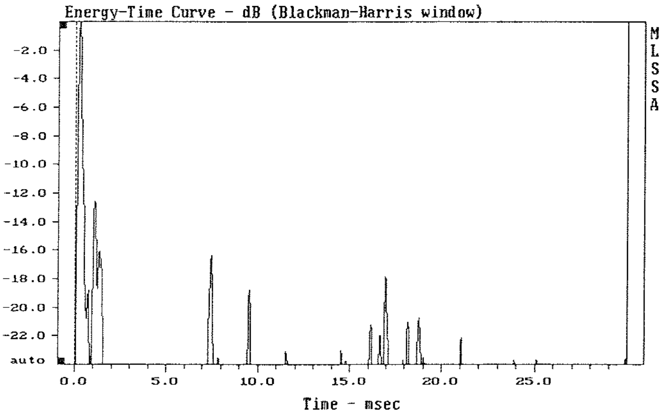


Fig. 6 - Energy-Time response for B12, left-hand loudspeaker.

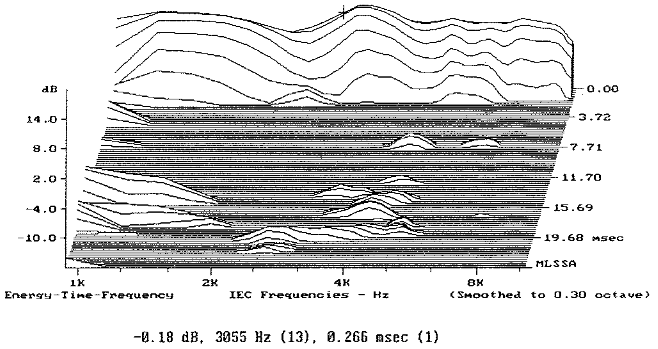


Fig. 7 - Energy-Frequency-Time response for B12, left-hand loudspeaker.

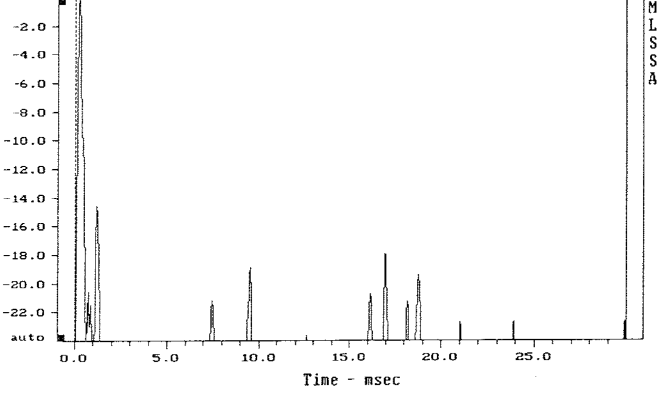


Fig. 8 - Energy-Time response for B12, left-hand loudspeaker, with absorber.

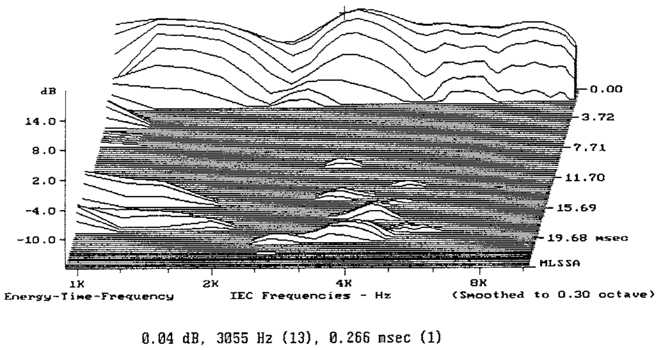


Fig. 9 - Energy-Frequency-Time response for B12, left-hand loudspeaker, with absorber.

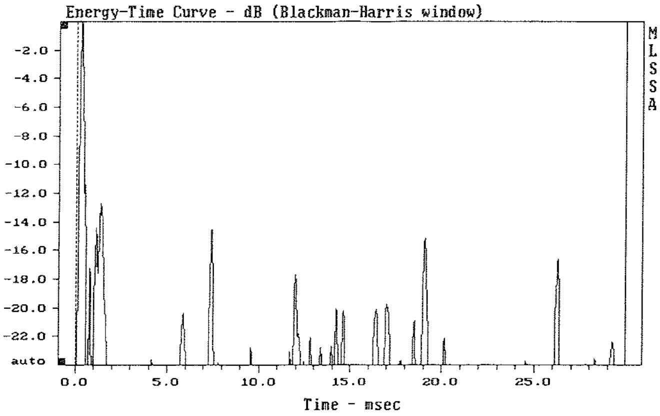


Fig. 10 - Energy-Time response for B12, right-hand loudspeaker.

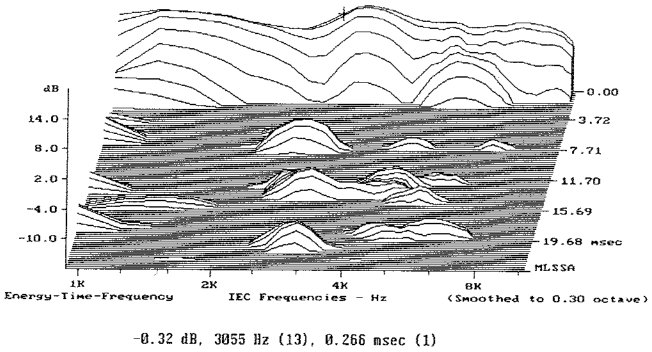


Fig. 11 - Energy-Frequency-Time response for B12, right-hand loudspeaker.

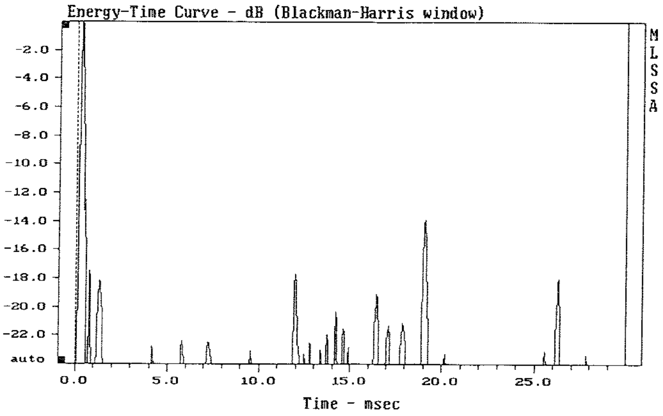


Fig. 12 - Energy-Time response for B12, right-hand loudspeaker, with absorber.

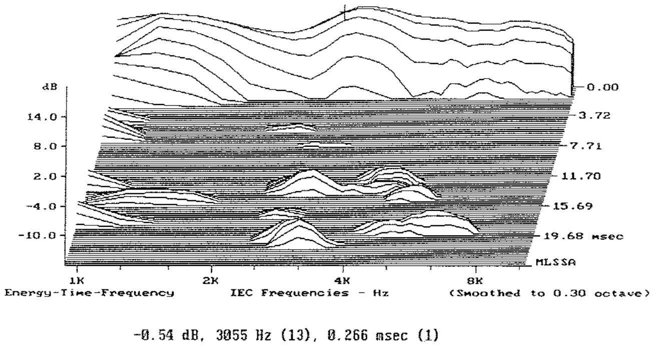


Fig. 13 - Energy-Frequency-Time response for B12, right-hand loudspeaker, with absorber.

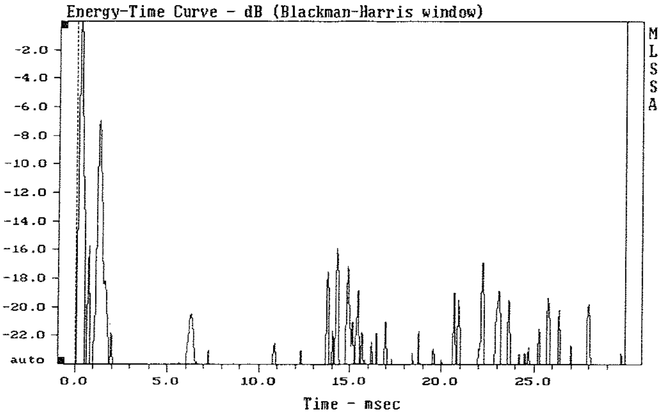


Fig. 14 - Energy-Time response for B13, left-hand loudspeaker.

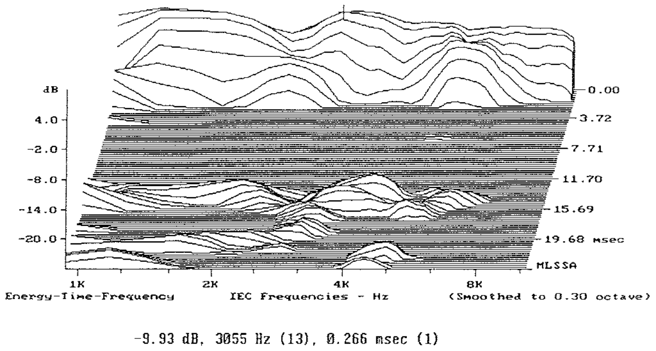


Fig. 15 - Energy-Frequency-Time response for B13, left-hand loudspeaker.

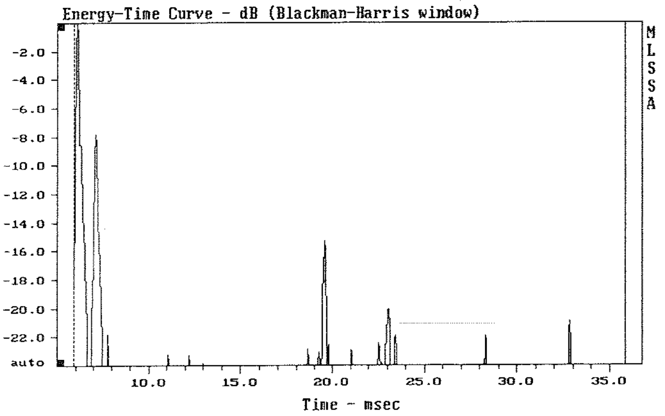


Fig. 16 - Energy-Time response for B13, right-hand loudspeaker.

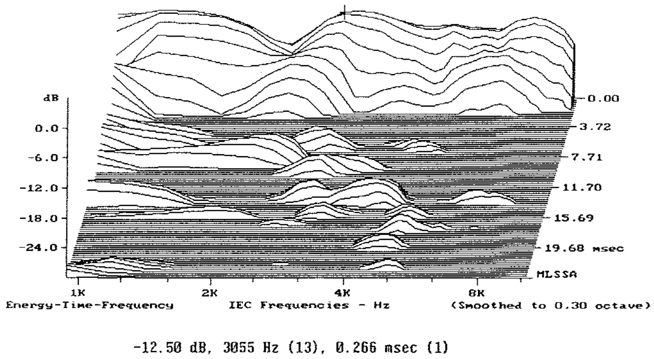


Fig. 17 - Energy-Frequency-Time response for B13, right-hand loudspeaker.

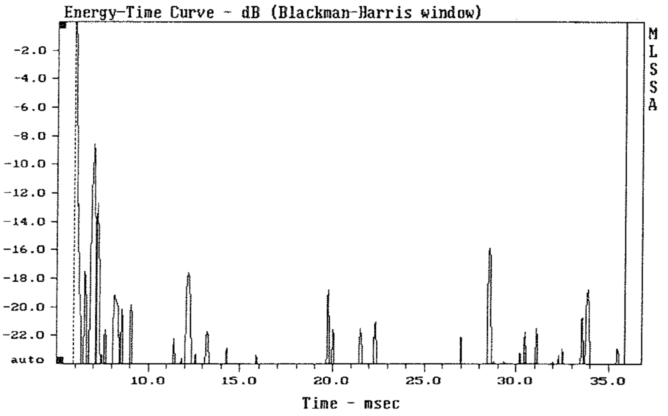


Fig. 18 - Energy-Time response for B14, left-hand loudspeaker.

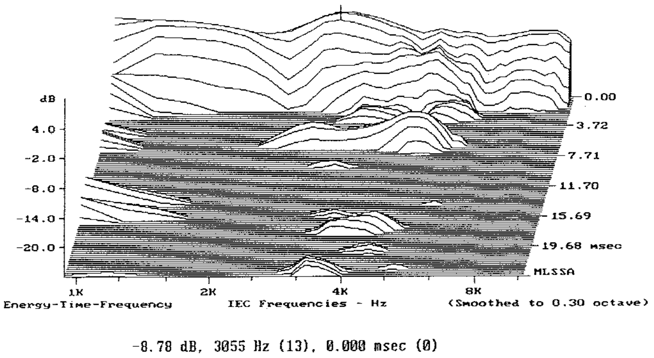


Fig. 19 - Energy-Frequency-Time response for B14, left-hand loudspeaker.

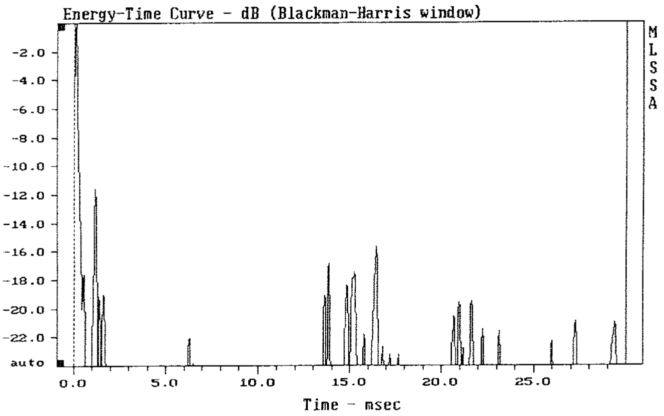


Fig. 20 - Energy-Time response for B14, right-hand loudspeaker.

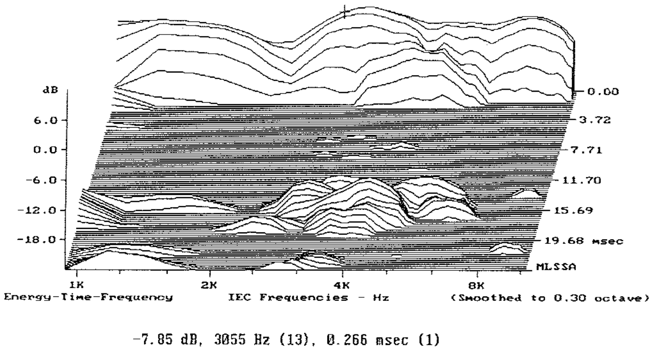


Fig. 21 - Energy-Frequency-Time response for B14, right-hand loudspeaker.

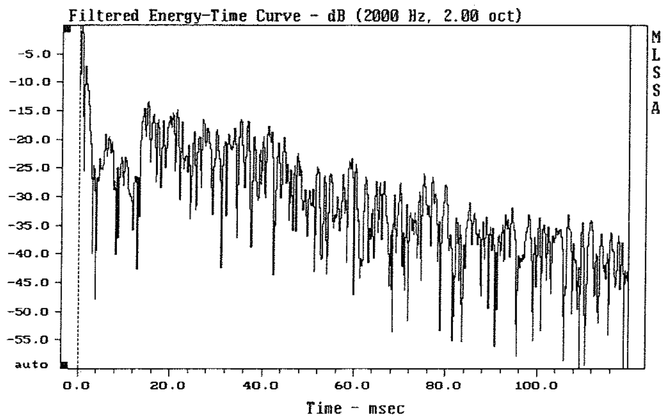


Fig. 22 - Energy-Time response for B13, left-hand loudspeaker.

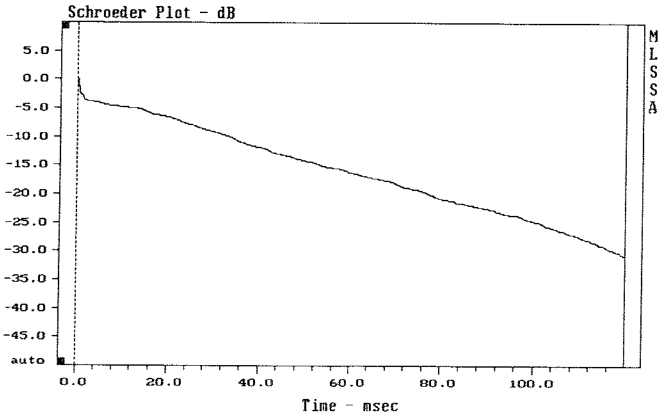


Fig. 23 - Schroeder integrated response plot B13, left-hand loudspeaker.

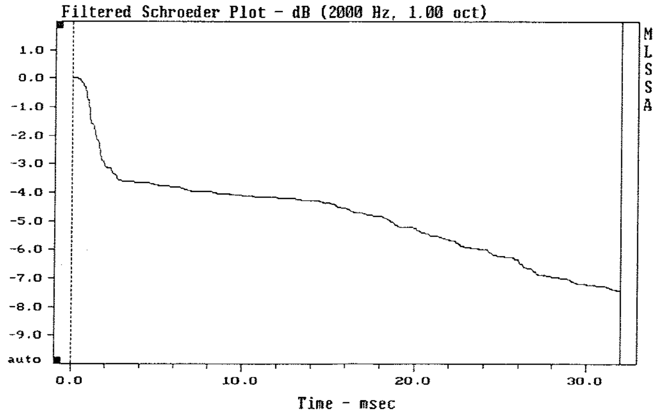


Fig. 24 - Schroeder integrated response plot, B12, left-hand loudspeaker, expanded axes.

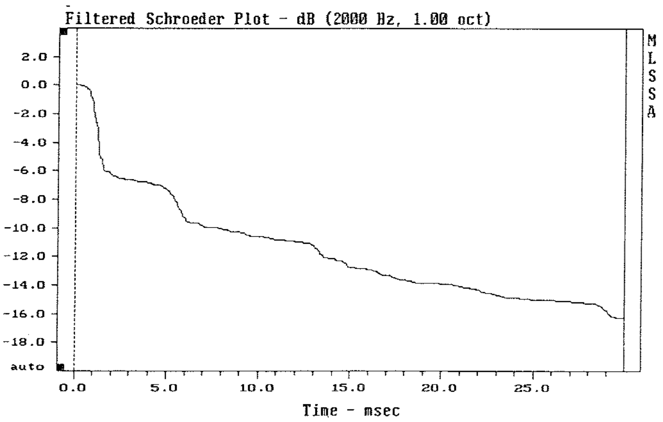


Fig. 25 - Schroeder integrated response plot, conventional design.

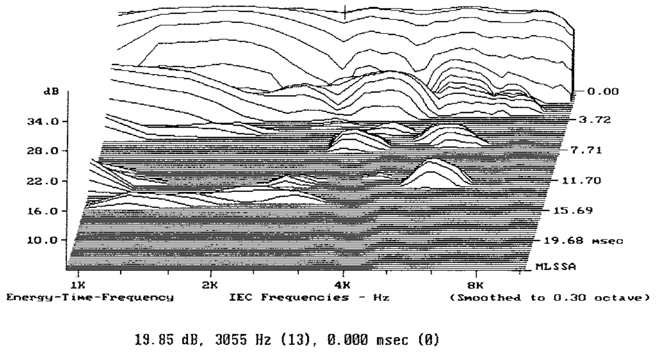


Fig. 26 - Energy-Frequency-Time response for Edinburgh Cubicle 1 (1991).

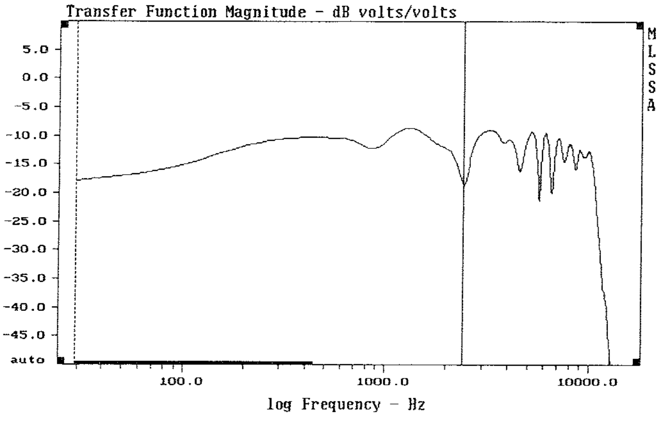


Fig. 27 - Frequency response plot for B13, left-hand loudspeaker, for first 3 ms.

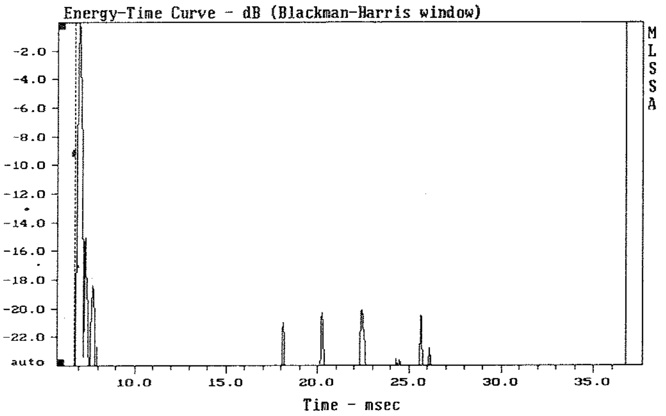


Fig. 28 - Energy-Time response for B12, left-hand loudspeaker, after change to loudspeaker height.

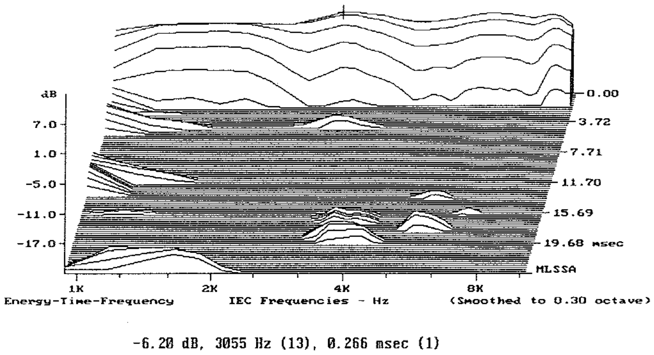


Fig. 29 - Energy-Frequency-Time response for B12, left-hand loudspeaker, after change to loudspeaker height.

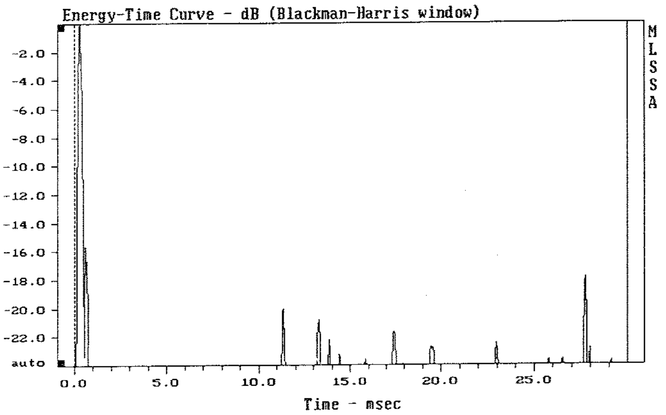


Fig. 30 - Energy-Time response for B12, right-hand loudspeaker, after change to loudspeaker height.

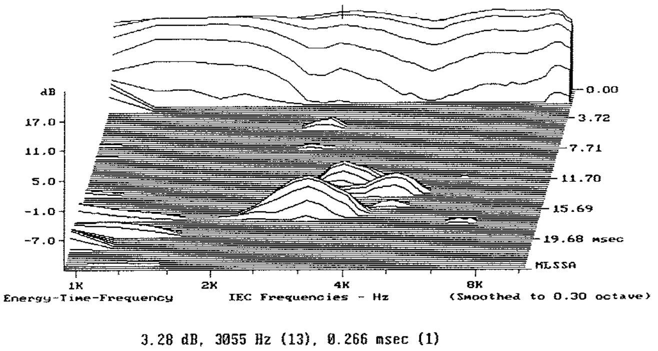


Fig. 31 - Energy-Frequency-Time response for B12, right-hand loudspeaker, after change to loudspeaker height.

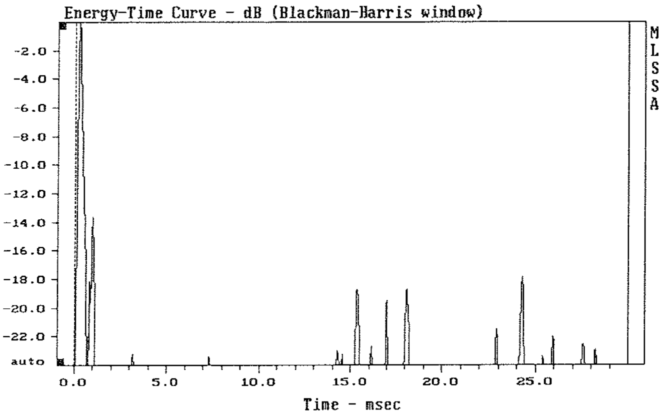


Fig. 32 - Energy-Time response for B13, left-hand loudspeaker, after change to loudspeaker height.

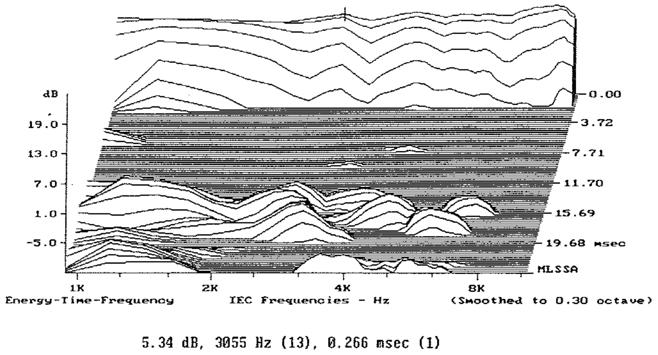


Fig. 33 - Energy-Frequency-Time response for B13, left-hand loudspeaker, after change to loudspeaker height.

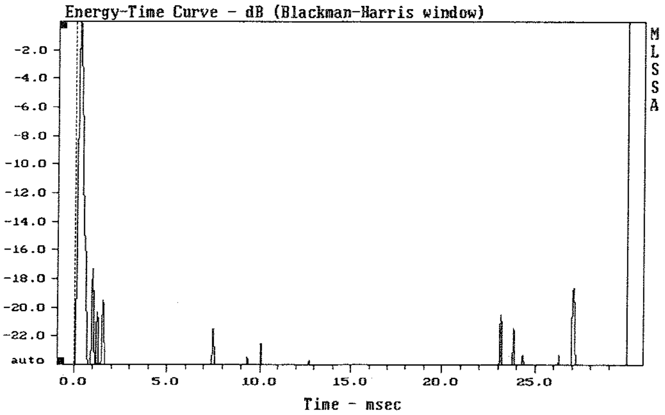


Fig. 34 - Energy-Time response for B13, right-hand loudspeaker, after change to loudspeaker height.

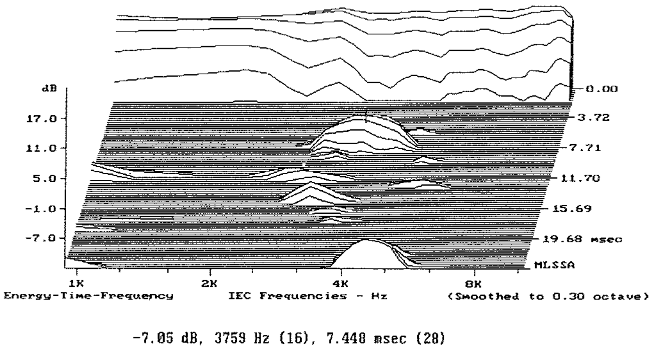


Fig. 35 - Energy-Frequency-Time response for B13, right-hand loudspeaker, after change to loudspeaker height.

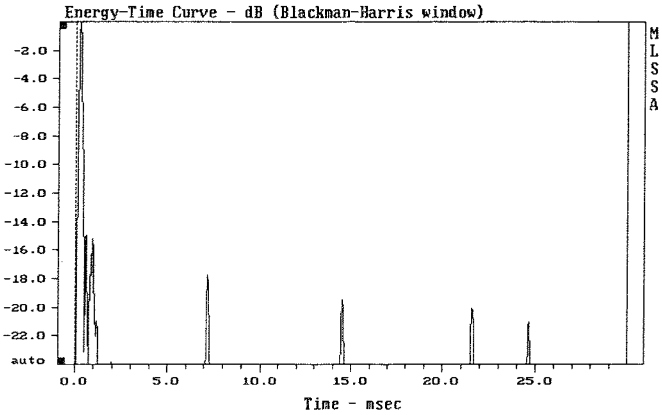


Fig. 36 - Energy-Time response for B14, left-hand loudspeaker, after change to loudspeaker height.

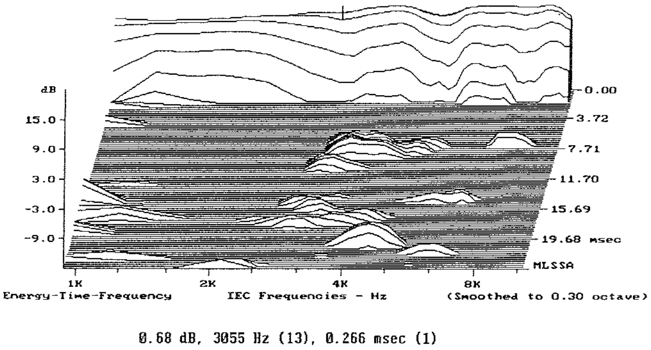


Fig. 37 - Energy-Frequency-Time response for B14, left-hand loudspeaker, after change to loudspeaker height.

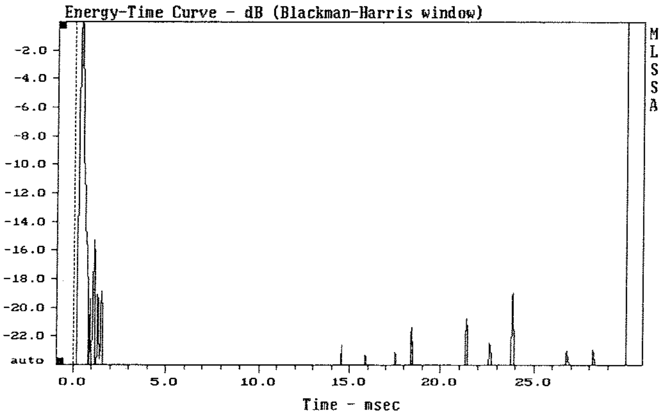


Fig. 38 - Energy-Time response for B14, right-hand loudspeaker, after change to loudspeaker height.

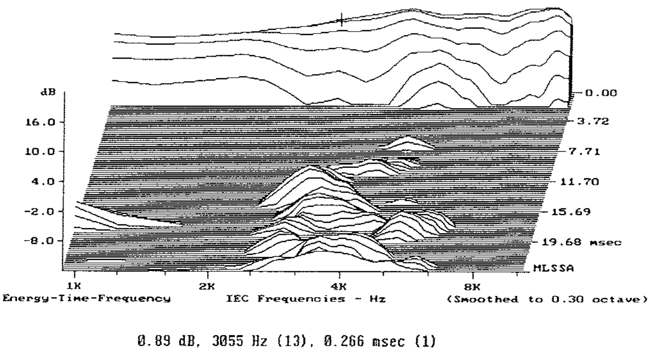


Fig. 39 - Energy-Frequency-Time response for B14, right-hand loudspeaker, after change to loudspeaker height.

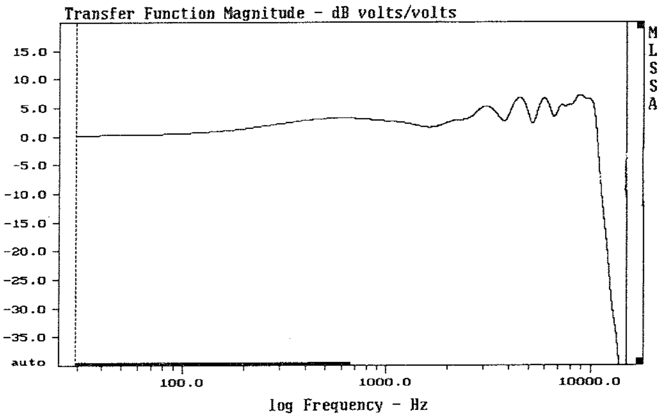


Fig. 40 - Frequency response plot for B13, left-hand loudspeaker for first 3 ms, after change to loudspeaker height.

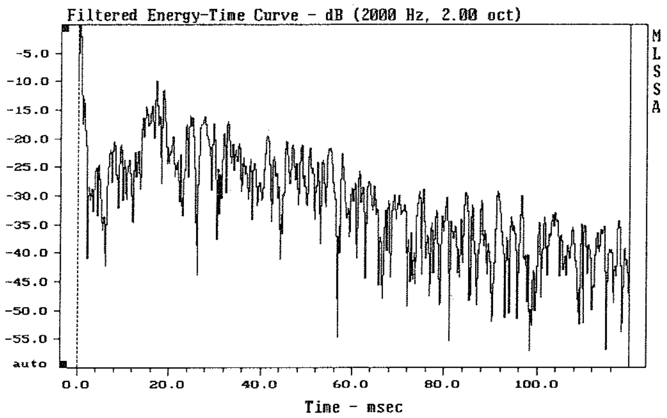


Fig. 41 - Energy-Time response for B13, left-hand loudspeaker over a longer time interval, after change to loudspeaker height.

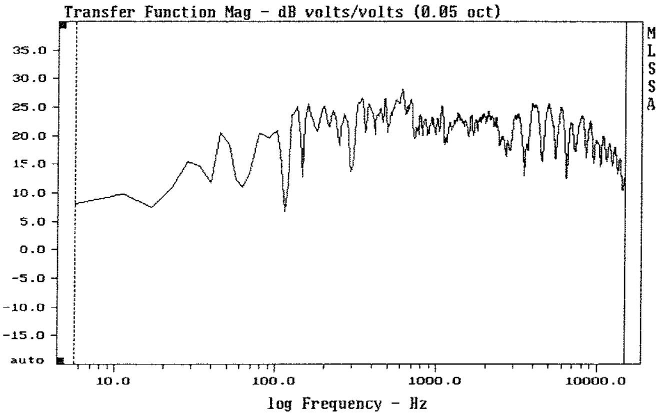


Fig. 42 - Measured 'comb-filter' response in B12, with loudspeakers in the wrong positions.

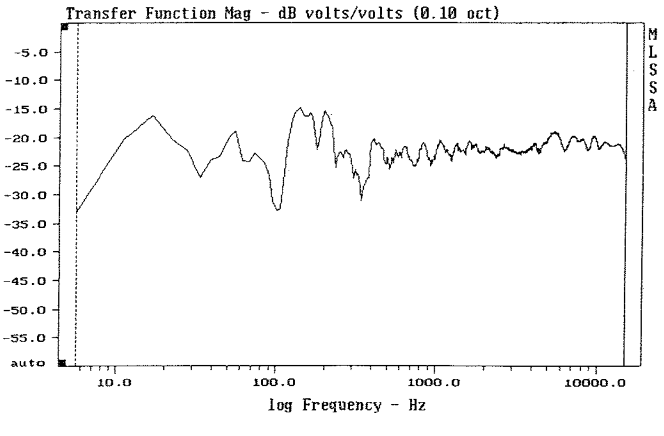


Fig. 43 - Frequency response plot for B12, left-hand loudspeaker, with new loudspeakers.

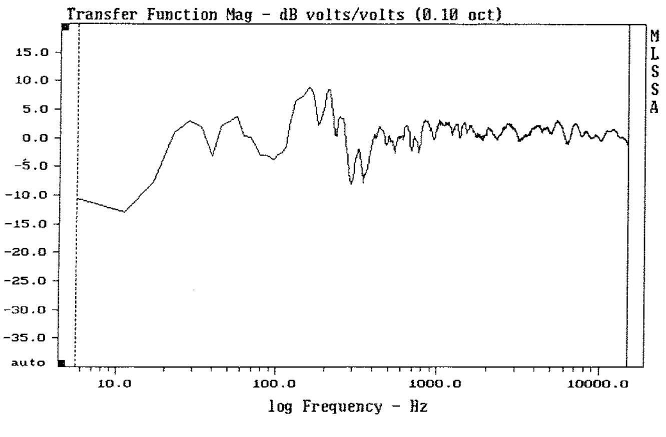


Fig. 44 - Frequency response plot for B12, right-hand loudspeaker, with new loudspeakers.

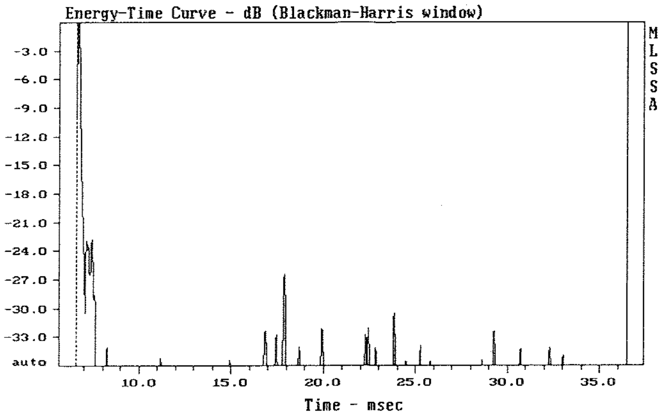


Fig. 45 - Energy-Time response for B12, left-hand loudspeaker, with new loudspeakers.

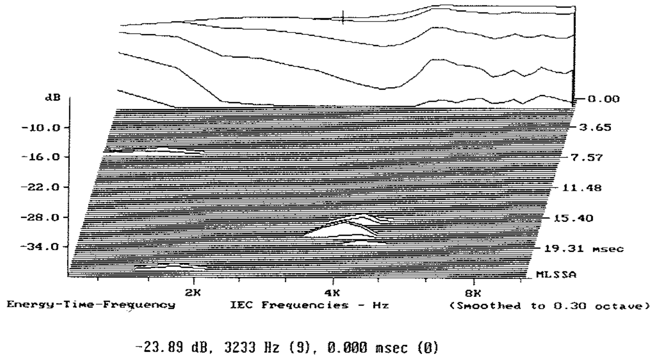


Fig. 46 - Energy-Frequency-Time response for B12, left-hand loudspeaker, with new loudspeakers.

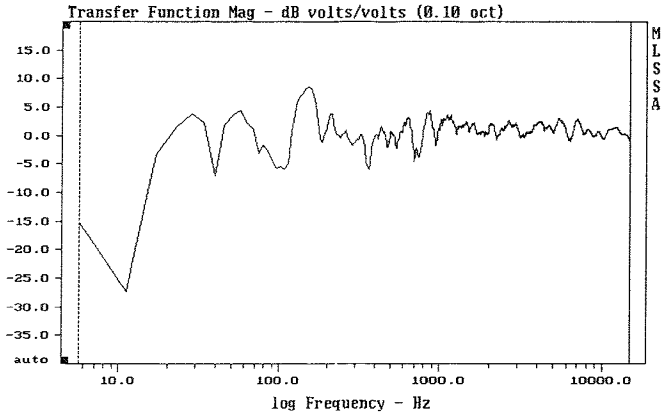


Fig. 47 - Frequency response plot for B12, right-hand loudspeaker, with low-frequency modular absorbers.

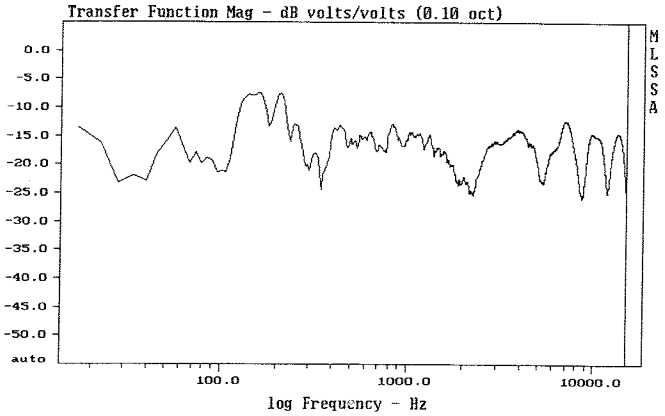


Fig. 48 - Frequency response plot for B12, both loudspeakers, at a position corresponding to 105 mm path-length difference.

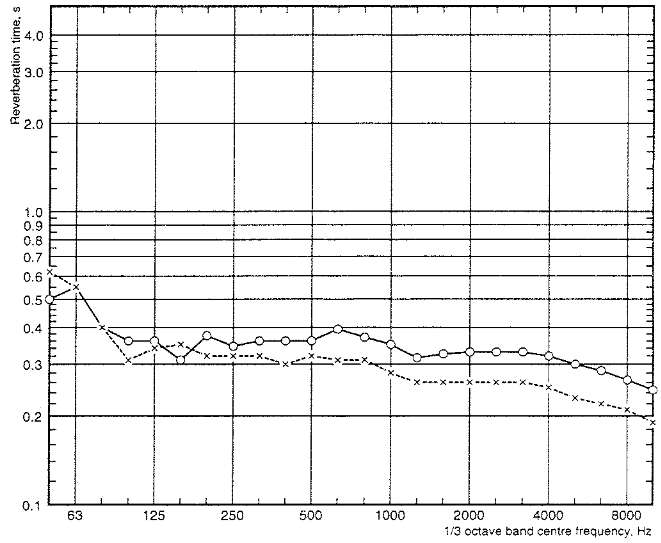


Fig. 49 - Reverberation times in B12
(a) as designed (○—○)
(b) with additional absorption at the front (×—×)

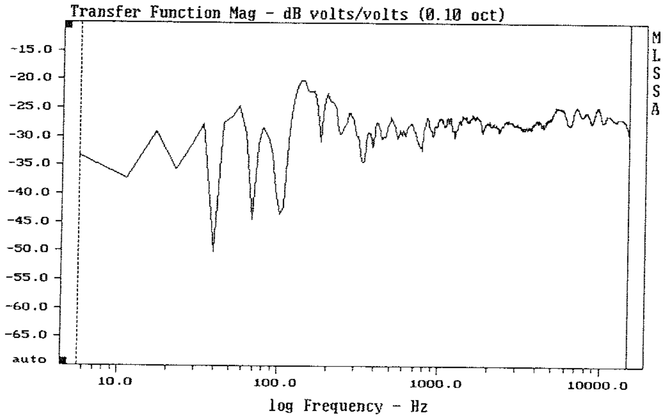


Fig. 50 - Frequency response plot for B12, left-hand loudspeaker, with additional acoustic absorption.

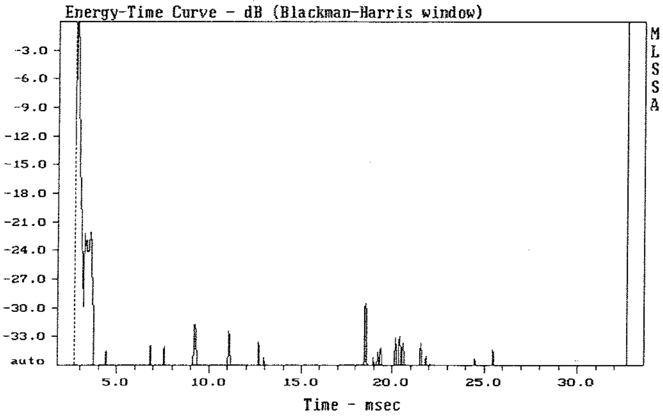


Fig. 51 - Energy-Time response for B12, left-hand loudspeaker, with new additional acoustic absorption.

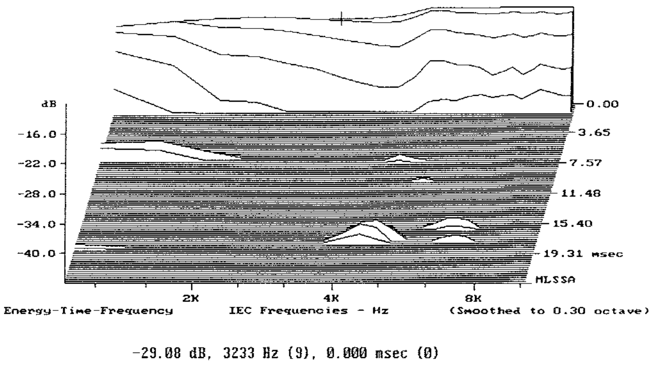


Fig. 52 - Energy-Frequency-Time response for B12, left-hand loudspeaker, with new additional acoustic absorption.

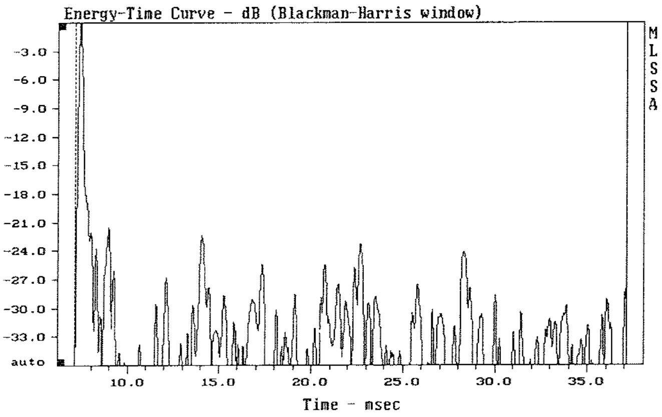


Fig. 53 - Energy-Time response for E1, left-hand loudspeaker.

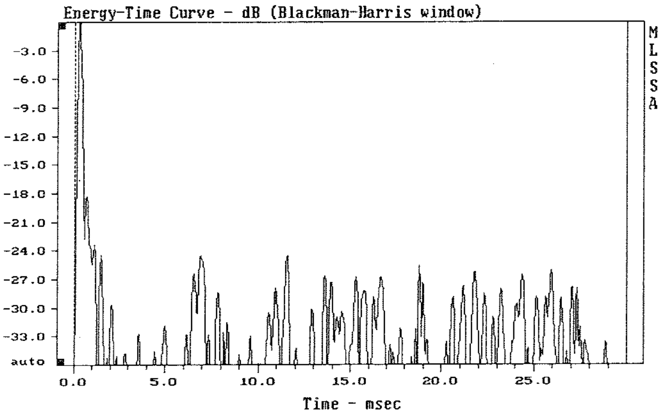


Fig. 54 - Energy-Time response for E1, right-hand loudspeaker.

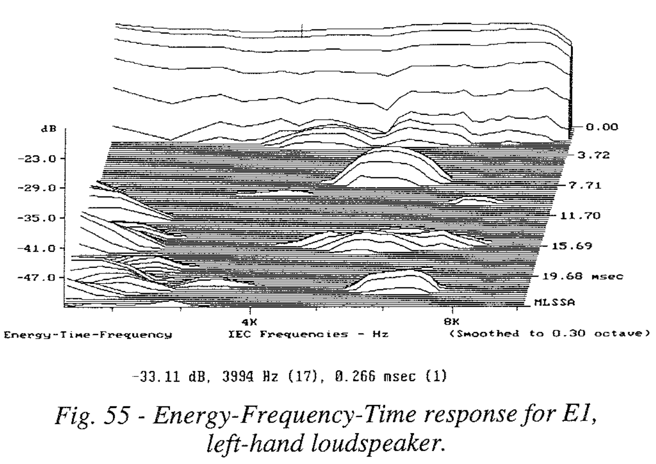


Fig. 55 - Energy-Frequency-Time response for E1, left-hand loudspeaker.

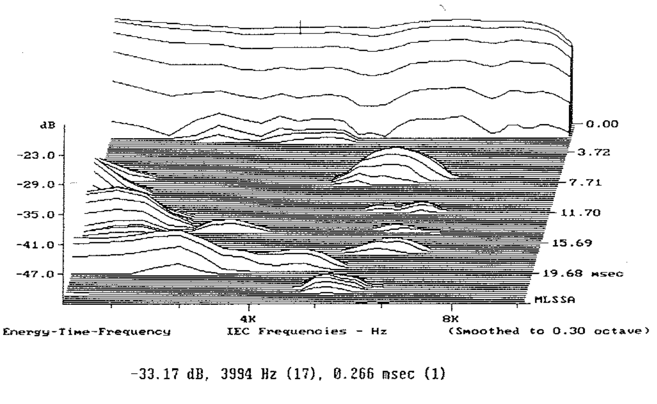


Fig. 56 - Energy-Frequency-Time response for E1, right-hand loudspeaker.

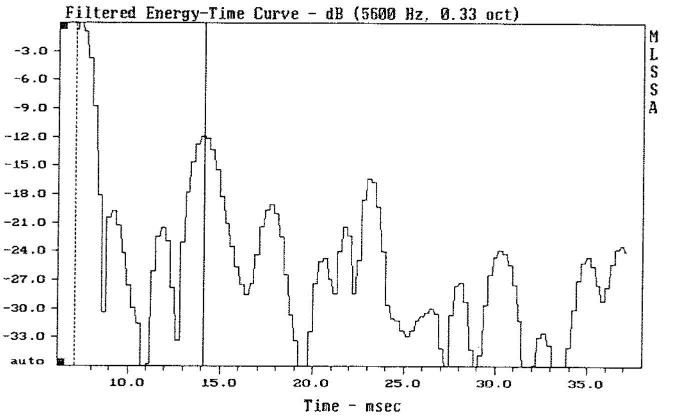


Fig. 57 - Filtered Energy-Time response for E1, left-hand loudspeaker, 5,800 Hz.

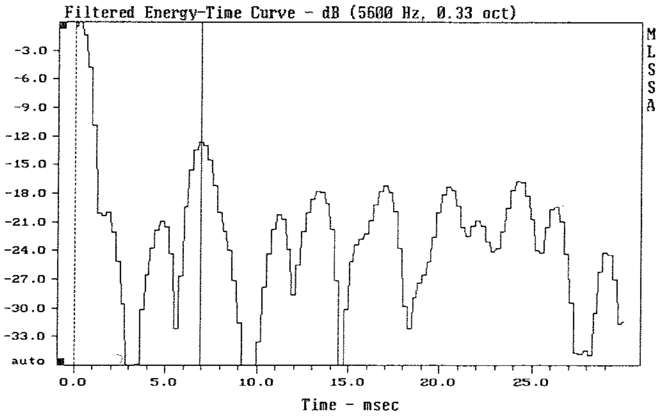


Fig. 58 - Filtered Energy-Time response for E1, right-hand loudspeaker, 5,800 Hz.